HIGHWAY RESEARCH REPORT

DYNAMIC TESTS OF THE CALIFORNIA TYPE 20 BRIDGE BARRIER RAIL SERIES XXIII

70-15

STATE OF CALIFORNIA

BUSINESS AND TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 636459

Prepared in Cooperation with the U.S. Department of Transportation, Bureau of Public Roads September 1970

STATE OF CALIFORNIA—TRANSPORTATION AGENCY RONALD REAGAN, *Governor*

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
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September 1970
Final Report
M & R No. 636459
D-4-83

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted for your consideration is a research report entitled:

DYNAMIC TESTS OF THE

CALIFORNIA TYPE 20 BRIDGE BARRIER RAIL

SERIES XXIII

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<u>J. H. Woodstrom and R. P. Hackett</u>
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<u>Assisted By</u>
J. J. Folsom, J. A. Halterman, and R. N. Doty

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

ABSTRACT

REFERENCE: Nordlin, E. F., Woodstrom, J. H., and Hackett, R. P., "Dynamic Tests of the California Type 20 Bridge Barrier Rail", State of California, Department of Public Works, Division of Highways, Materials and Research Department. Research Report 636459.

ABSTRACT: The results of five full scale vehicle impact tests into the California Type 20 Bridge Rail are reported. The Type 20 Bridge Rail is a rigid barrier system which incorporates a 27 inch high reinforced concrete parapet with a traffic-side contour very similar to that utilized for the New Jersey type concrete median barrier. A 2-inch by 6-inch by 1/4-inch thick structural steel tube rail is placed 12 inches above the top of this parapet, thus giving an over-all barrier height of 39 inches.

Tests were conducted at speeds of from 45 to 66 mph and at impact angles of 7, 15, and 25 degrees. The test results indicated that this system will retain and redirect a 4900 lb. passenger vehicle impacting at speeds up to 65 mph and at angles of from 7 to 25 degrees with the barrier. Vehicle damage resulting from high speed impacts will be negligible at angles up to 7 degrees, will increase to moderate as impact angles approach 15 degrees, and will be severe at 25 degree impact angles.

Vehicular decelerations sustained during 65 mph impacts into this system will be in excess of those generally judged tolerable for unrestrained occupants except at impacting angles less than about 7 degrees. Occupants restrained by lap belts will probably sustain little or no injuries at shallow impact angles such as 7 degrees but moderate to severe injuries at impact angles approaching 25 degrees. Fully restrained occupants (seat belt and shoulder harness) should sustain no more than moderate injuries at impact angles up to 25 degrees. Thus the value of the sloped face with regard to both vehicular deceleration and vehicular damage is greatest for flat angle impacts and diminishes as the angle of impact increases.

KEY WORDS: Bridge rail, barriers, concrete, dynamic tests, impact tests.

ABSTRACT

[illegible] Department of Public Works [illegible]

[illegible] from 15 to 45 mph, and [illegible]. The test vehicles [illegible]

[illegible] high speed impacts will [illegible] will increase to [illegible]

[illegible] sustained during [illegible] in excess of those generally [illegible] should sustain no [illegible]

ACKNOWLEDGEMENTS

This work was accomplished in cooperation with the United States Department of Transportation, Federal Highway Administration, Bureau of Public Roads, as Item D-4-83 of Work Program HPR-PR-1(6), Part 2, Research. The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Bureau of Public Roads.

The dedication and competence of the following staff members of the Materials and Research Department made the successful testing described herein possible:

1. Roger Pelkey, Joseph Eagan, Lee Staus, Al Rybicki, and Roger Stoughton inspected the barrier construction, completed the test site preparation, completed the instrumentation of the test vehicles and the dummy occupants of these test vehicles, conducted the tests, accumulated and assisted in the analysis of physical data, prepared the movie report of this testing, and assisted in the preparation of this final report.

2. William Chow, Richard Johnson, Merle Wilson, and Delmar Gans calibrated the test vehicle and dummy instrumentation, assembled and operated the data acquisition and processing systems, and assisted in the interpretation of the data obtained with these electronic systems.

3. Robert Mortensen and Lewis Green provided both data and documentary photographic coverage of the tests.

[illegible]

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I. INTRODUCTION

Highway engineers are continually striving to improve their product. Their efforts along this line are motivated by a concern for safety, aesthetics, and a desire to give the public the greatest value for its tax dollar. In the area of highway barrier systems, significant improvements have and are being made as new concepts and designs are developed and tested.

The first California Division of Highways vehicle impact tests on bridge rails were conducted in the mid and late 1950's[1,2]. These tests were initiated because of the serious operational deficiencies, primarily structural, that were developing with the bridge barrier rails then in use as heavier, higher speed vehicles took to the highways.

As a result of these tests, the California Division of Highways, in about 1958, adopted a design designated as the California Type 1 Bridge Barrier Rail (Figure 1 below. Also see Exhibit 1 for comparative drawings of this and several other traffic barrier designs that are mentioned below). This design is 36-inches high and is composed of a single 5-inch diameter metal pipe railing mounted 15-inches above the top of a 21-inch high solid reinforced concrete parapet.

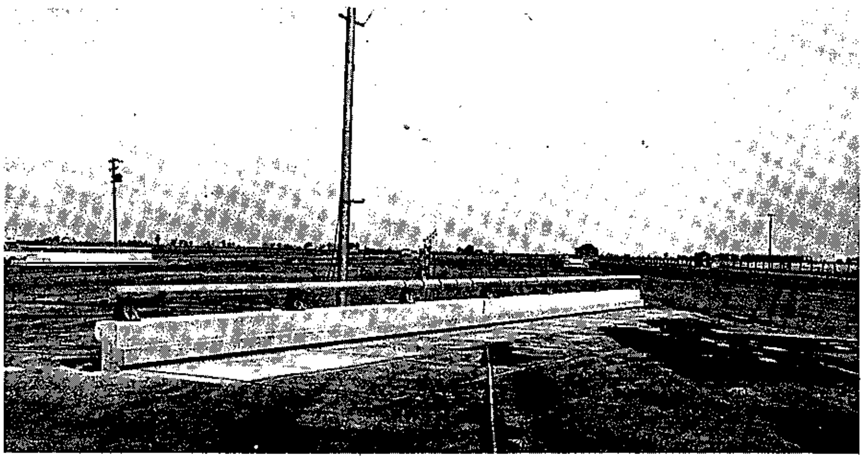


FIGURE 1

Although the Type 1 rail is structurally adequate, operational experience indicated that in desert areas sand tended to pile up against the solid parapet wall. It was also found that visibility through this railing is somewhat restricted, both for the motorist on the bridge wishing to view the surrounding scenery and from a safety standpoint for the motorist needing adequate sight distance from an approach ramp adjacent to the structure.

These considerations led in 1965-66 to the design, testing, and subsequent use of the California Type 8 Bridge Rail[3] (Figure 2, below). This design is composed of two 2- by 6-inch steel rectangular tube rails mounted 15-inches and 27-inches high on welded, open-type steel posts spaced 10-ft. on centers.

FIGURE 2

From the standpoint of structural adequacy and appearance, the Type 8 design performed well. However, operational experience has indicated that on higher structures, motorists tend to shy away from this low, open, fragile appearing barrier and thus crowd the inner lanes of traffic. Consequently, in 1968-69 the California Type 9 Bridge Barrier Rail was developed and tested[4] (Figure 3 and Exhibit 1). It consists of a single 2- by 6-inch steel rectangular tube rail attached to welded steel posts mounted on a 15-inch high concrete parapet for an over-all barrier height of 27-inches.

The Type 9 design, with its low concrete parapet wall, single narrow rectangular tube rail, and low over-all height, has proven through operational experience to be an effective and pleasant appearing bridge railing that provides visibility nearly equal to the Type 8 design.

However, reports from New Jersey[5] and subsequent tests by the California Division of Highways in 1966-67[6] indicated that the

New Jersey concrete median barrier (Exhibit 1) showed definite promise of reducing the damage sustained by vehicles striking it at the more prevalent flat angles of impact. This characteristic was also reported by General Motors[7] in tests they conducted on a bridge barrier containing a parapet contour similar to the New Jersey barrier (Exhibit 1). The effectivness of the lower sloped surface in reducing vehicle damage and decelerations had also been observed operationally in several experimental installations of the New Jersey concrete median barrier in California.

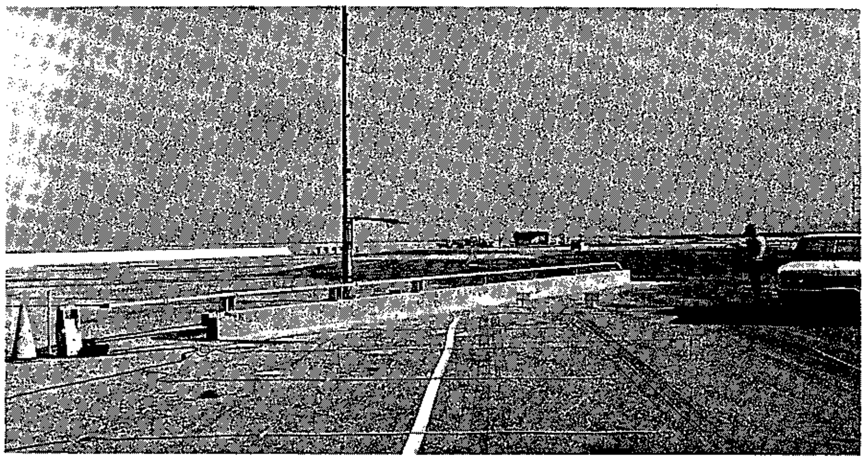


FIGURE 3

Consequently, the Bridge Department of the California Division of Highways designed the Type 20 Bridge Rail (Figure 4, below, and Exhibit 1). This design incorporates a single steel rail mounted 12 inches above the top of a 27-inch high concrete parapet. The rail is rectangular tubing identical to that used in the Type 9 design. The parapet wall has a traffic-side profile almost identical to the New Jersey median barrier.

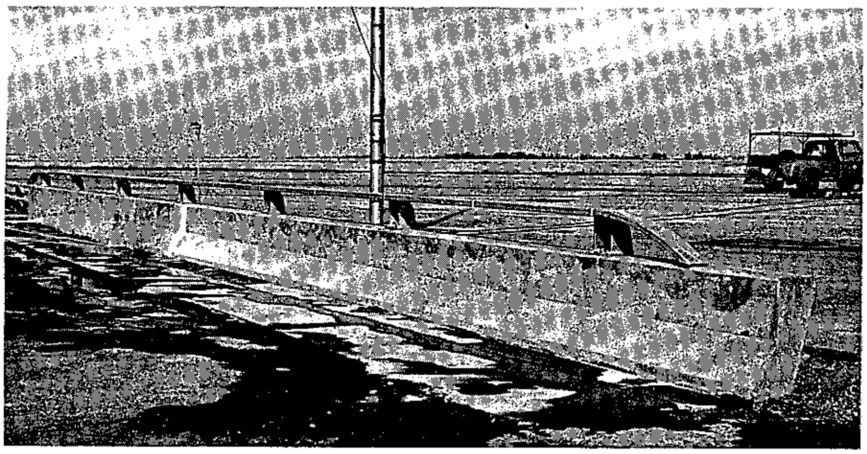


FIGURE 4

The Type 20 design provides better "see through" characteristics than the General Motors design because the over-all height is about 16 inches lower, the concrete parapet height is about 5 inches lower, and the steel rail is narrower. Visibility through the Type 20 bridge rail is not as good as through the Type 9 design. However, it appears to be adequate. Thus the advantages of the lower sloped face appear to justify the use of the Type 20 design.

Five full scale vehicle impact tests of this Type 20 bridge rail are reported herein.

II. OBJECTIVES

The objectives of this research project were as follows:

1. Test the ability of the California Type 20 bridge barrier rail to:

    a. Retain and redirect, in a stable manner, a medium weight passenger car traveling 60-65 mph and impacting at angles of from 7° to 25° while sustaining little or no damage.

    b. Minimize the damage and deceleration sustained by the vehicle during these collisions; and

    c. Prevent excessive rebound of the vehicle back across the traveled way and/or other behavior hazardous to traffic near the point of impact.

2. Evaluate the aesthetic and visibility properties of the Type 20 bridge barrier railing.

III. COCLUSIONS

The following conclusions are based on an analysis of the results of the full scale vehicle impact tests conducted during this test series:

1. The Type 20 bridge barrier rail will retain and redirect a 4900 pound passenger car impacting at speeds up to 65 mph and approach angles up to 25 degrees. The vehicle will remain stable and upright during redirection and little or no barrier damage will be sustained.

2. In more common shallow angle impacts such as 7 degrees, little or no vehicular damage will be sustained. Occupant injuries will vary from minor (seat belt and shoulder harness) to moderate (no restraint). Thus, the contoured traffic face of the Type 20 bridge barrier rail parapet definitely minimizes the collision severity at shallow angles of impact.

   When the angle of impact is between 15 degrees and 25 degrees, a vehicle striking the Type 20 bridge rail at a speed of 64 mph or greater will sustain severe damage and occupant injuries will vary from minor to moderate if a seat belt and shoulder harness is used to severe if no restraints are used. The Type 20 bridge barrier rail appears to offer little or no advantage over other rigid bridge barrier rails now in use in California when impacted at these larger approach angles.

3. The impacting vehicle tended to hug the bridge rail in all tests rather than rebound sharply off the rail. This is particularly true at flatter impact angles. In four of the five tests, the exit angle was 3 degrees or less. Thus, the Type 20 rail appears to be equal or superior to other types of rigid bridge barrier rails in eliminating the secondary hazard of rebound.

4. The Type 20 bridge rail offers no aesthetic improvements over those types of bridge rails now in use in California. In addition, its see-through properties are inferior to at least one bridge rail now in use in California. However, the use of this barrier design seems to be justified by the significant collision severity decrease that was observed at flat impact angles.

5. No design modifications were made to the test barrier during the tests and none are recommended.

IV. TEST CONDITIONS

A. Barrier Design and Construction

The design of the Type 20 bridge rail was developed by the California Division of Highways Bridge Department and submitted to the Materials and Research Department for testing. Prior to the construction of a full scale test installation, there was some concern that the 27-inch high concrete parapet was too high for sufficient lateral visibility. Thus, a full scale, plywood mock-up was erected on an existing bridge next to some Type 1 bridge barrier railing to compare the see-through qualities of the two designs (see Figure 5). After the mock-up was reviewed and the initial dimensions approved, the design details for the Type 20 bridge barrier railing were finalized.

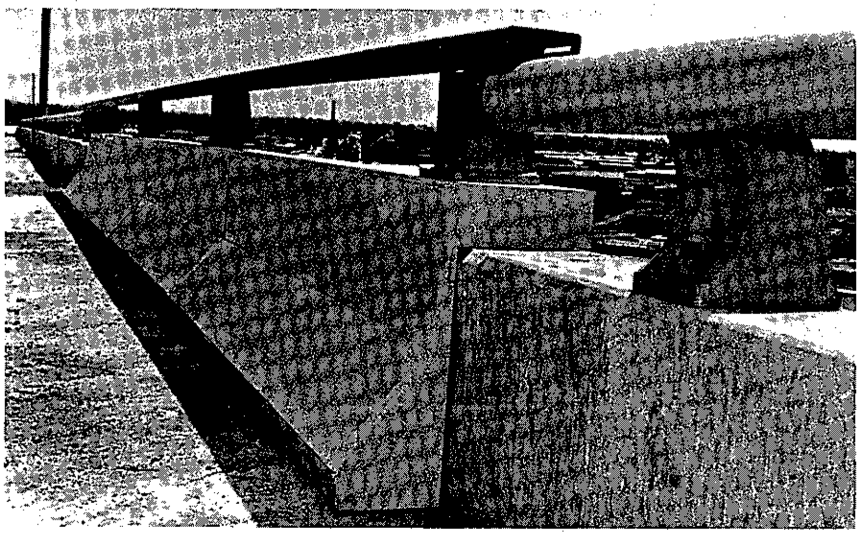


FIGURE 5

The Type 20 design consists of the current California Standard Type 9 Bridge Barrier Rail posts and rail mounted on a reinforced concrete parapet design adapted from the New Jersey median barrier. The steel rail portion of this barrier was fabricated with 6- by 2-inch by 12.02-lb. structural steel tubing conforming to the requirements of ASTM Designation A500, Grade B. The posts were fabricated of structural steel conforming to the requirements of ASTM Designation A36.

The minimum length of each steel rail segment was 20 ft. except at the ends where the steel rail was bent down in a 5 ft. radius to meet the top of the parapet. The 3/4-inch welded stud rail-to-post connector and the interior sleeve rail splice, proven effective in a previous test series[4], were again employed. The fabricated steel posts were spaced at 10-ft. centers and were secured to the concrete parapet with one 3/4-inch diameter by 8-inch long and one 1-inch diameter by 12-inch long high strength bolts cast in the concrete. These high strength bolts conformed to the requirements of ASTM Designation A325. The concrete portion of the barrier consisted of a 27-inch high by 67-ft. long reinforced concrete parapet constructed on a reinforced concrete cantilevered deck. The total barrier height was 39-inches from the bridge deck to the top of the steel rail member. The deck and parapet reinforcing, as well as the other details of the Type 20 bridge barrier rail, are shown on Exhibit 2.

This system was designed in accordance with the requirements of the "Standard Specifications for Highway Bridges" adopted by the American Association of State Highway Officials in 1969. The test section was built on an unused runway at a small airport near Lincoln, California.

B. Vehicle Instrumentation

The test vehicles used in this study were 1966 Dodge sedans weighing approximately 4900 lbs., including two anthropometric dummies and on-board instrumentation. These vehicles were retired California Highway Patrol sedans and were modified for remote radio control as follows:

1. A solenoid-valve actuated CO_2 system was connected to the brake line for remote brake application. With 700 psi in the accumulator tank, the brakes could be locked in less than 100 milliseconds.

2. The accelerator pedal was "floorboarded" using a small electric motor and a linkage between the pedal and the motor. The motor was activated by manually throwing a switch mounted on top of the rear fender of the test car.

3. The ignition system was connected to the brake relay in a failsafe interlock system. When the brakes were applied, the ignition was switched off. Any loss of radio signal or failure in the transmitting or receiving equipment would automatically energize the brake relay and switch off the ignition.

4. The gas tank was removed and replaced with a heavy duty one-gallon fuel tank to minimize the chance of a fire and/or explosion.

5. Steering was accomplished with a 400 inch-ounce stepping motor (mounted on the dashboard on the passenger side) through a V-belt driven pulley attached to the steering shaft.

6. Three wet-cell storage batteries (6-volt, 8-volt, and 12-volt), mounted on the floor of the rear seat compartment, supplied power to the remote control equipment.

7. The radio control receiver, tone actuated relays, steering pulse, and handi-talkie were mounted on a plywood panel mounted in the trunk compartment. Whip antennas were mounted on the rear fenders.

Photographs of some of this equipment are shown in Reference 8. Control of the vehicle during the approach was accomplished by an operator following approximately 200 feet behind the test vehicle in a control car equipped with a tone transmission system.

Two anthropometric dummies were placed in the front seat of the test vehicle and restrained with conventional lap belts for all five tests. The driver, "Stan", weighs about 165 lbs. (50th percentile male); the passenger, "Sam", weighs about 210 lbs. (95th percentile male).

C. Photographic Coverage

All the tests were photographed with high speed (250-400 frames per second) Photosonic cameras which were manually actuated from a central control console. These cameras were located to the front, rear, and side of the point of impact, on a tower directly above the point of impact, and in the crash car. Most of the Photosonic data film had red-orange timing pips projected on it at a rate of 1000 per second. These pips were then counted to determine the frame rates of the cameras. Targets were attached to the vehicle body and a target board bolted to the roof of the vehicle to facilitate data reduction of the film using a Vanguard Motion Analyzer. Another Photosonic camera was located in the rear of the vehicle to film movement of the dummies. This camera was actuated by a switch, mounted on the rear bumper of the test vehicle, that was tripped using a 50-foot length of nylon line anchored to the pavement behind the vehicle.

Documentary coverage consisted of high speed and normal speed motion picture coverage during the tests plus motion pictures, still photographs, and slides taken before and after each test. A scaffold mounted Hulcher camera with a speed of 20 frames per second was also used for documentary coverage of the tests. Selected frames from this film are on the data sheets included in Part V, Test Results, of this report. Five tape switches, placed perpendicular to the vehicle path at ten-foot intervals leading into the point of impact, were actuated by the tires of the test vehicle and triggered a series of flashbulbs located in view of all data cameras. These flashbulbs were used for correlation between all stationary cameras and for the determination of the impact velocity.

Flashbulbs mounted on top of the rear fenders of the test vehicle were used to establish the vehicle location and the time at which the brakes were applied. The bulbs also served to alert the control car driver that the test car's brakes had been applied. These flashbulbs were fired when the brake actuating relay was closed by either radio equipment failure or the remote operator.

D. Data Acquisition and Processing

The instrumentation system used for all five tests was the Wyle Accident Simulation Measurement System on loan from the Bureau of Public Roads[9]. It consisted of seven channels of FM telemetry for the crash vehicle and dummies and seven channels of hardwire equipment for the barrier. The system included seven accelerometers and two seat belt force transducers and all the necessary signal conditioning equipment. The dynamic data from these transducers were recorded on a 14 channel analog magnetic tape recorder which was also a part of the system.

The location and description of the instrumentation of the test vehicle for Tests 232, 234, and 235 are shown on page 11. The instrumentation layouts for Tests 231 and 233 are not shown because the accelerometer records for these tests were considered invalid. Location "A" is at the longitudinal center of gravity of the test vehicle.

Tape switches were placed adjacent to the flashbulb tape switches used for synchronization of the cameras and determination of the impact velocity 10 ft. and 30 ft. in front of the point of impact. The front and rear tires of the vehicle activated these switches. This caused an "event marker" signal to be recorded, along with the accelerometer data, on the tape recorder. Concurrently, a 100 millisecond (ms) time cycle was also recorded on the tape recorder. These two channels provided a secondary method of measuring impact velocity and a method of referencing the electronic data to impact.

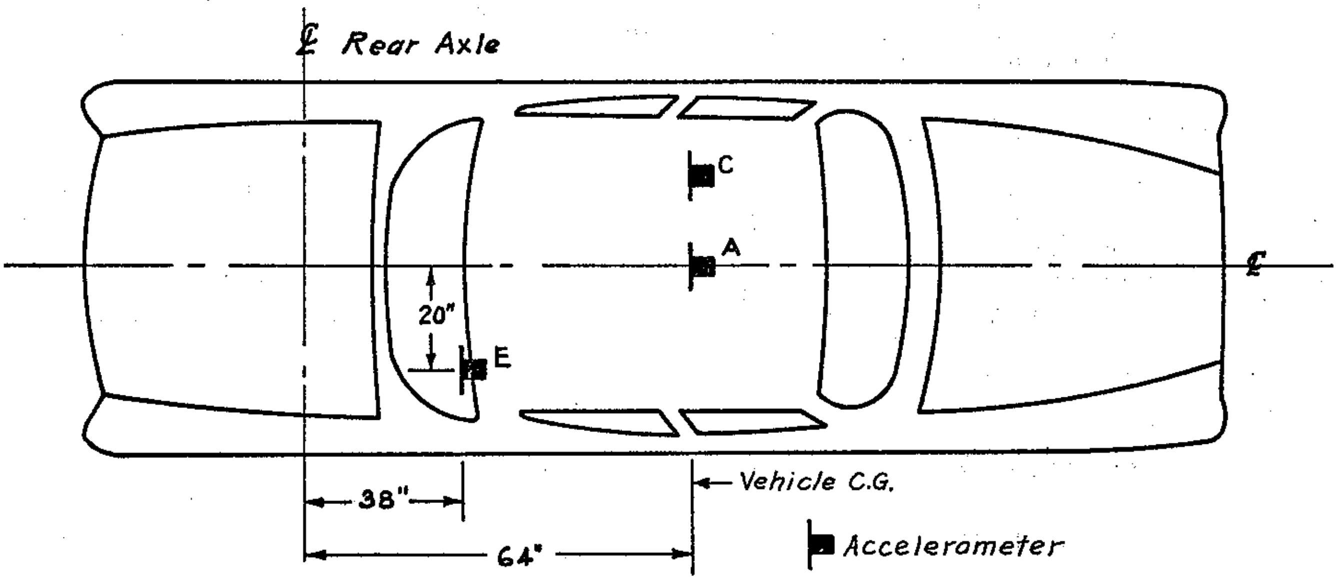
After a test, the data on the tape was played back through a visicorder which produced a trace (line) on paper. Each paper record contained one data channel trace, the front and rear wheel event marker "pips", and the 100 ms time cycle trace.

The accelerometer data was also filtered at 100 Hertz. This filtered trace was then reproduced in the same manner as the "raw" data. The data was filtered in an attempt to separate the "noise" from the actual deceleration. The filtration also facilitated comparison of different accelerometer records. See Appendix A for a discussion of filtering.

CALIFORNIA DIVISION OF HIGHWAYS

VEHICLE INSTRUMENTATION

TYPE 20 BRIDGE BARRIER RAIL TESTS



Test #232

CHANNEL NO.	LOCATION[1]	DESCRIPTION[2,3]
1	A	100 "G" longitudinal accelerometer (T)
2	A	100 "G" lateral accelerometer (T)
3	E	100 "G" longitudinal accelerometer (T)
4	E	50 "G" lateral accelerometer (T)
5	C	50 "G" longitudinal accelerometer (T)
6	C	50 "G" lateral accelerometer (T)
7	C	50 "G" vertical accelerometer (T)
8	E	100 "G" longitudinal accelerometer (U)
9	E	100 "G" lateral accelerometer (U)

Tests #234 & #235

1	A	100 "G" longitudinal accelerometer (T)
2	A	100 "G" lateral accelerometer (T)
3	E	100 "G" longitudinal accelerometer (T)
4		Same as Channel 3
5	E	50 "G" lateral accelerometer (T)
6	C	50 "G" lateral accelerometer (T)
7	C	50 "G" longitudinal accelerometer (T)
8	E	100 "G" longitudinal accelerometer (U)
9	E	50 "G" lateral accelerometer (U)

Notes:

[1] A and E on vehicle floor; C on back of dummy's chest cavity.

[2] (T) = telementry, (U) = umbilical cord.

[3] All transducers were unbonded strain gage type accelerometers. Channels 1-7 were Statham Model A514TC and Channels 8 and 9 were Statham Model A400TC.

The time at which impact occurred was established from the high speed movies and then located on the record of accelerometer data. The cause of accelerometer data events could then be determined, at least in some cases, through study of the vehicular and dummy kinematics recorded on the film at the same point in time.

E. Test Parameters

The test guidelines established by the Highway Research Board Committee on Guardrails and Guide Posts[10] specify the use of a 4,000-lb.± vehicle, an impact velocity of 60 mph, and an impact angle of 25 degrees. A heavier vehicle (4,900 lbs.) traveling at approximately 65 mph was used for these tests because it was felt that these higher values more nearly represented the more severe conditions now being encountered on California's freeways.

The five tests were identical except as follows:

Test No.	Speed (MPH)	Angle of Impact
231	45	7°
232	66	7°
233	64	15°
234	64	7°
235	66	25°

V. TEST RESULTS

Introduction

The following pages contain descriptions of the five full scale tests. In all these tests, the point of impact was within 6 ft. of the concrete parapet expansion joint to test this critical point of discontinuity.

Tire skid marks and other scuff marks on the barrier parapet were studied after each test to determine the vehicle's behavior. After this examination, the marks were covered with white paint to prepare the barrier for the next test.

The decelerations reported in the descriptions of each test are averages of the highest average decelerations sustained over a 50 ms period. The measurements were taken using Statham strain gage type accelerometers mounted on the floor of the vehicular passenger compartment and in the back of the dummy chest cavity. A discussion of the processing and interpretation of this data is included in Appendix A of this report.

Test No. 231

Test No. 231 was conducted to evaluate the effectiveness of the Type 20 bridge barrier rail when impacted at a flat approach angle and a moderate speed. The vehicle impacted the barrier approximately 27.5 ft. from the upstream end at a speed of 45 mph and at an approach angle of 7 degrees. After impacting the barrier, the test vehicle was smoothly redirected parallel to the barrier. Vehicle barrier contact was maintained for the remaining 40 ft. ± of barrier, after which the vehicle traveled an additional 150 ft. before coming to a stop.

Maximum vehicular rise was approximately 16 inches. There was minor sheet metal damage sustained by the test vehicle and slight surface cracks sustained by the barrier (see Figures 6 and 7 below). No determination of the electronically measured deceleration could be made due to the poor quality of the instrumentation data. See the following page for additional test data, information, and photographs.

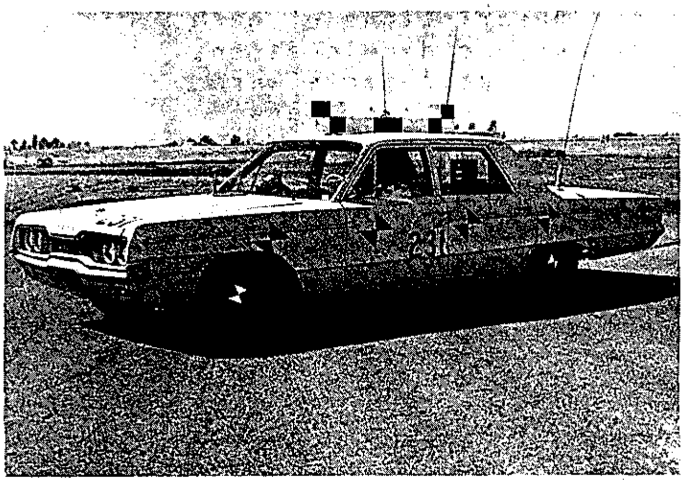


FIGURE 6

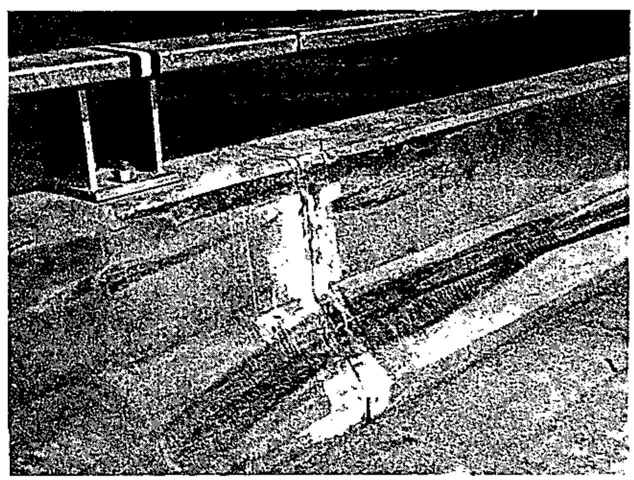


FIGURE 7

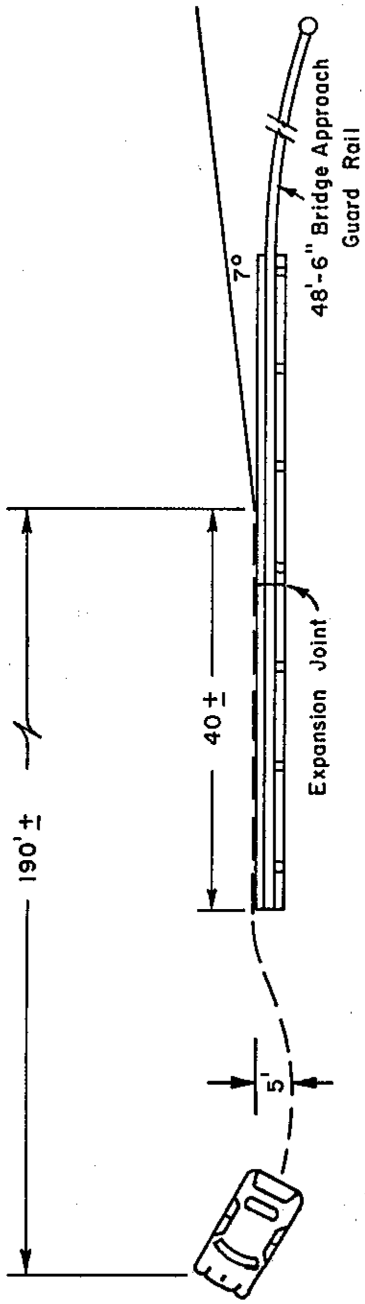
TEST 231

Impact +0.02 Sec.

I + 0.21 Sec.

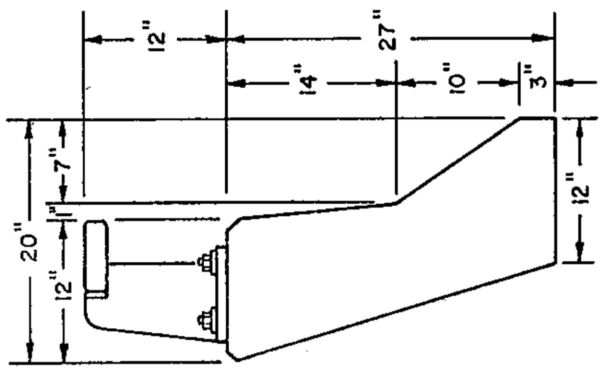
I + 0.53 Sec.

I + 0.62 Sec



BARRIER TESTED . . . . Type 20 Bridge Rail
LENGTH OF INSTALLATION . . . . 67'±
PASSENGER COMPARTMENT DECEL. (Highest 50 ms average) Long. * Lat. *
MAXIMUM VEHICLE RISE . . . . 16"
EXIT ANGLE . . . . 0°
BARRIER DAMAGE . . . . Negligible
*EXCESSIVE INTERFERENCE IN SIGNAL.

TEST NO. 231
DATE 10-2-69
VEHICLE . . . . 1966 Dodge Sedan
SPEED . . . . 45 mph
IMPACT ANGLE . . . . 7°
VEHICLE WEIGHT (Incl./dummys & instrumentation) . . . . 4980 Lbs
DUMMY RESTRAINT . . . . Lap Belt



Test No. 232

The same vehicle used for Test No. 231 was used for Test No. 232 with no repairs. Test No. 232 was also a 7 degree impact but the impact velocity was increased to 66 mph. Impact was again about 27.5 feet from the upstream end of the test barrier. After impact, the vehicle traveled along the barrier for 27 feet and then left the barrier at an exit angle of 1 degree. During this test the maximum vehicle rise was 16 inches. Vehicle damage was very minor, and there was no significant structural damage sustained by the barrier (see Figures 8 and 9 below). The damaged windshield and grill were caused by a second collision with a section of scaffold. A maximum 50 ms average deceleration of 4.8 G's lateral (average of 2 data channels) was measured on the floor of the vehicular passenger compartment. This deceleration did not exceed the tolerance level, as defined in Appendix A, for a lap-belted occupant. None of the longitudinal deceleration data was considered accurate. See the following page for additional test data, information, and photographs.

FIGURE 8

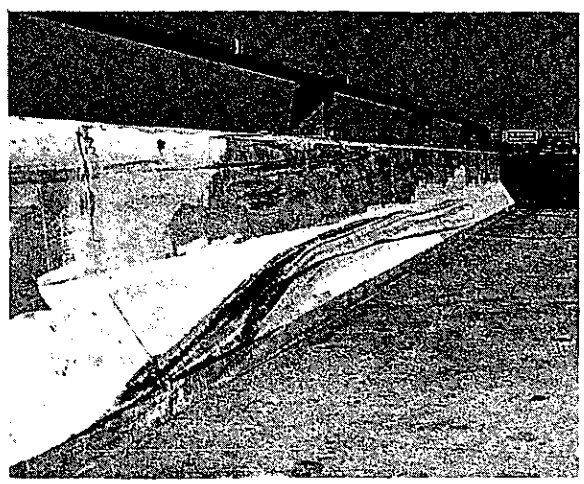
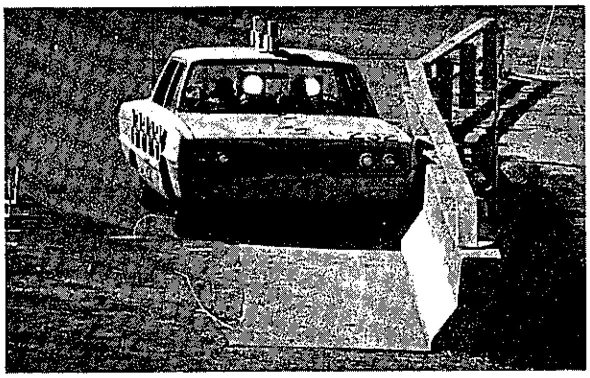
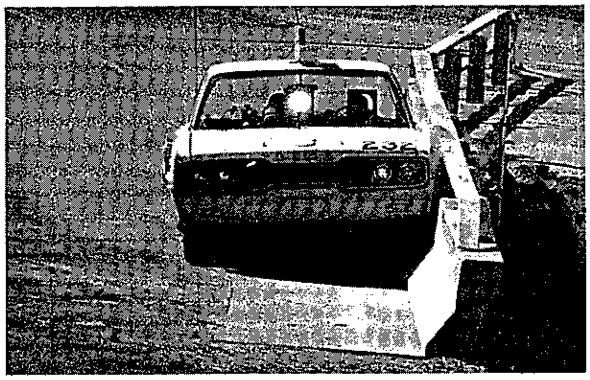


FIGURE 9

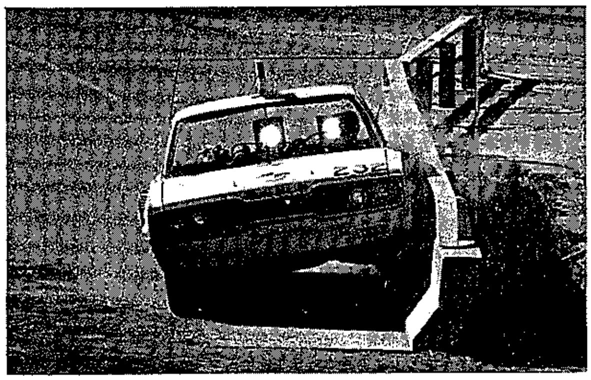
TEST 232



Impact + 0.03 Sec.

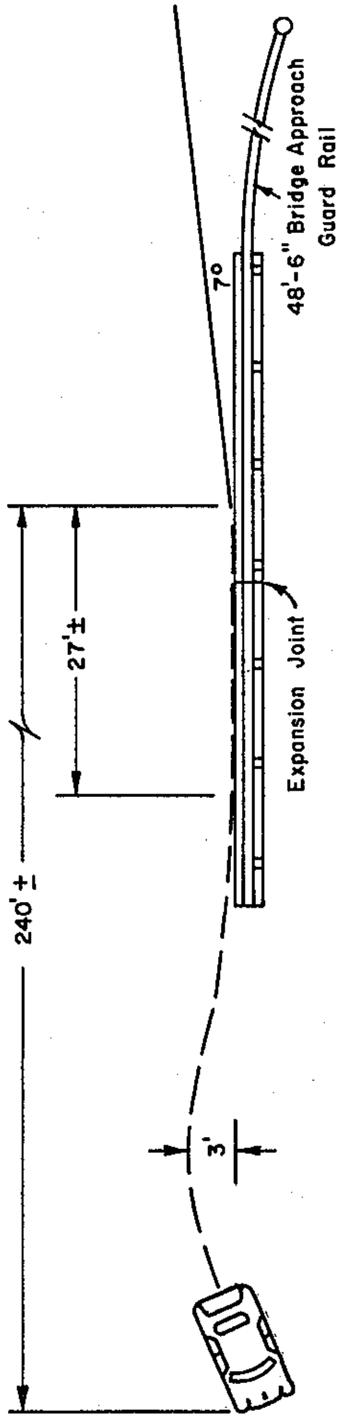


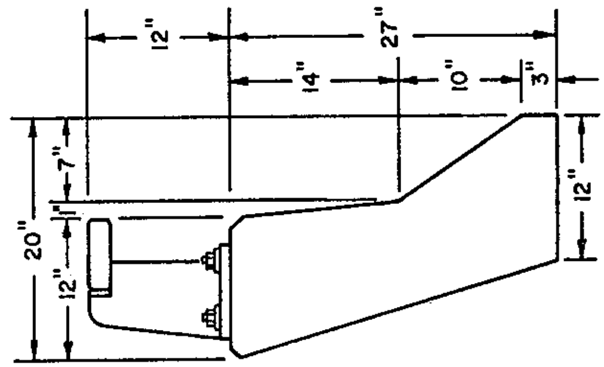
I + 0.17 Sec.



I + 0.30 Sec.

I + 0.44 Sec.





BARRIER TESTED	Type 20 Bridge Rail
LENGTH OF INSTALLATION	67'±
PASSENGER COMPARTMENT DECEL. (Highest 50 ms average)	Long. * Lat. 4.8 G's
MAXIMUM VEHICLE RISE	16"
EXIT ANGLE	1°
BARRIER DAMAGE	Negligible

* ERRONEOUS DATA

TEST NO.	232
DATE	10-2-69
VEHICLE	1966 Dodge Sedan
SPEED	66 mph
IMPACT ANGLE	7°
VEHICLE WEIGHT (Incl./dummys & instrumentation)	4980 Lbs
DUMMY RESTRAINT	Lap Belt

Test No. 233

The vehicle used for Tests 231 and 232 was again re-used for this test, a 64 mph, 15 degree impact. Impact occurred about 27.5 feet from the upstream end of the barrier. After maintaining contact with the barrier for approximately 19 feet, the test vehicle left the barrier at an exit angle of 10 degrees. Vehicle rise was small as it appeared that the steel railing held the test vehicle down during the redirection. This penetration underneath the steel railing is indicative of the decreasing effect of the contoured concrete surface at larger impact angles. There was no tendency for the vehicle to roll or jump. The left front end and undercarriage of the vehicle were severely damaged (see Figure 10 below). Minor spalling of the concrete parapet also occurred (see Figure 11 below). No measurement of vehicular or dummy deceleration was obtained due to an apparent instrumentation malfunction. See the following page for additional test data, information, and photographs.

FIGURE 10

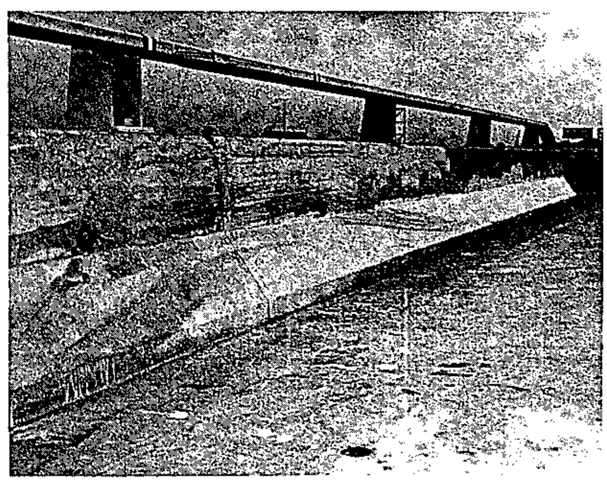
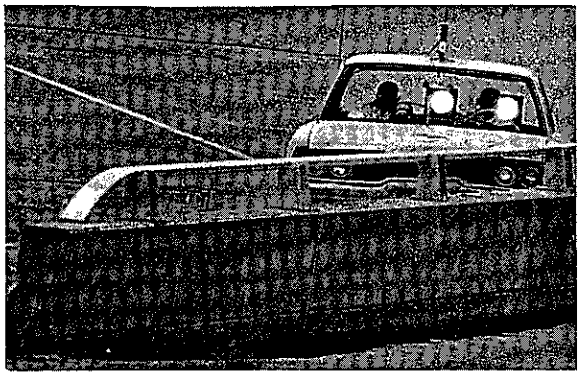
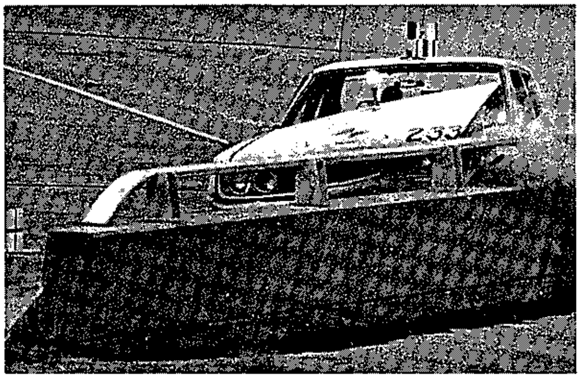


FIGURE 11

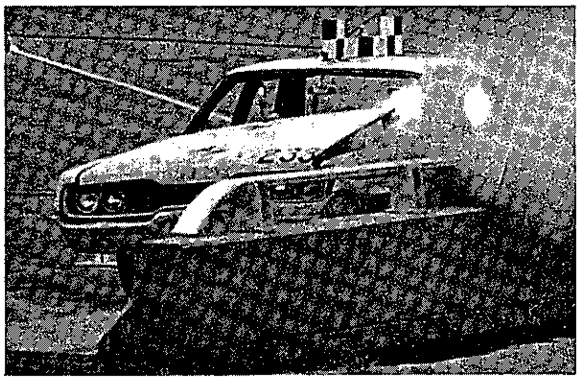
TEST 233



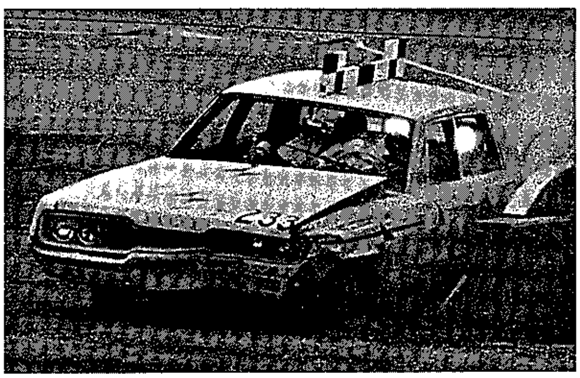
IMPACT



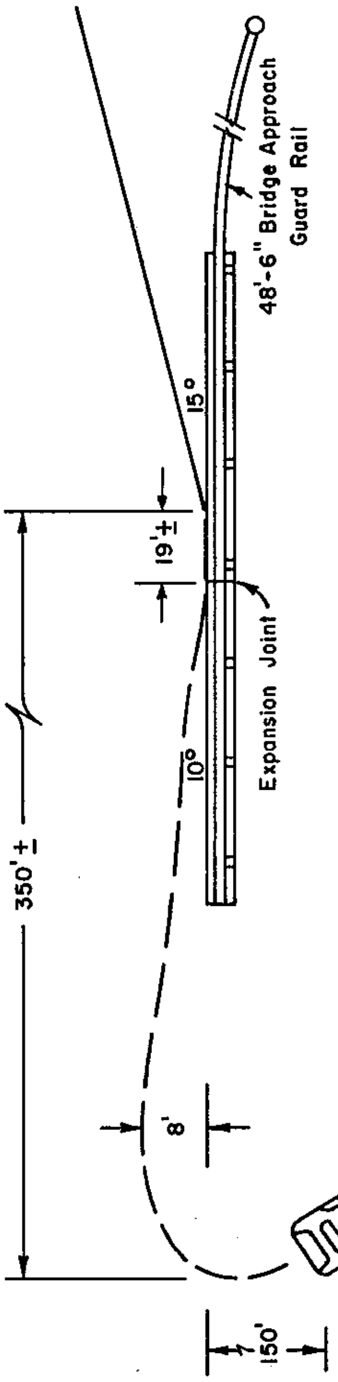
I + 0.09 Sec.



I + 0.23 Sec.



I + 0.46 Sec.

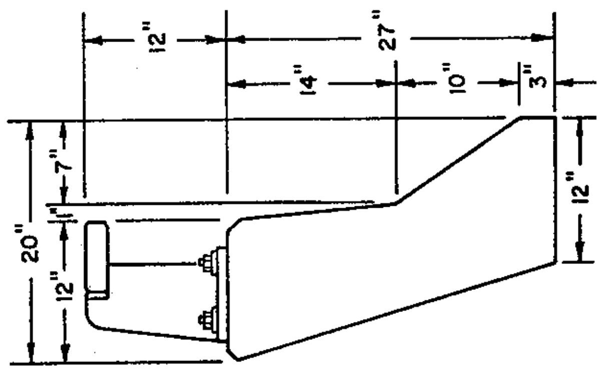


TEST NO.	233
DATE	10-8-69
VEHICLE	1966 Dodge Sedan
SPEED	64 mph
IMPACT ANGLE	15°
VEHICLE WEIGHT (Incl./dummys & instrumentation)	4900 Lbs.†
DUMMY RESTRAINT	Lap Belt

BARRIER TESTED	Type 20 Bridge Rail
LENGTH OF INSTALLATION	67'±
PASSENGER COMPARTMENT DECEL. (Highest 50 ms average)	Long. * Lat. *
MAXIMUM VEHICLE RISE	Negligible
EXIT ANGLE	10°
BARRIER DAMAGE	Negligible

* INSTRUMENTATION MALFUNCTION

† VEHICLE GAS TANK REMOVED



Test No. 234

Test No. 234 was performed to substantiate the results of Test No. 232. This correlation was felt necessary because the vehicular rise noted during Test No. 232 (16 inches) was substantially less than that noted during a previous 7 degree/65 mph test (Test 161B) of the New Jersey type concrete median barrier[6] (see Figures 12 and 13 below).

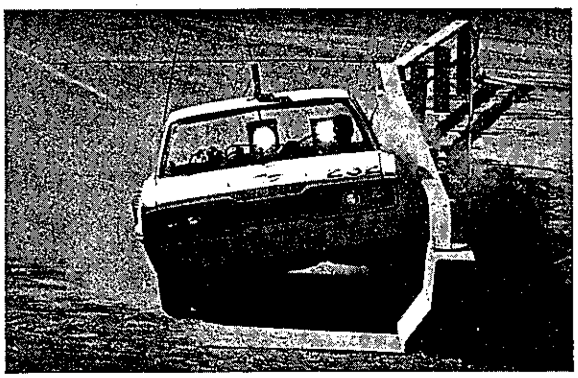


FIGURE 12

Test No. 232

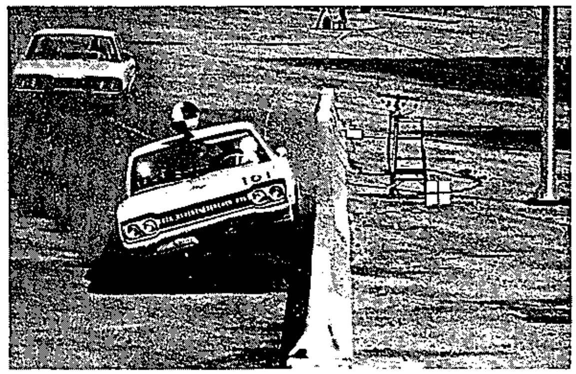


FIGURE 13

Test No. 161B

During Test No. 234 (7 degrees/64 mph), impact was again located approximately 27.5 feet from the upstream end of the barrier. The maximum rise of the test vehicle was approximately 18 inches. After impacting the barrier, the vehicle traveled along the barrier for approximately 30 feet before exiting at an angle of 1 degree.

Vehicle damage was limited to minor scrapes along the left side (see Figure 14 below). Barrier damage was very minor (see Figure 15 below). The maximum 50 ms average decelerations measured on the floor of the vehicular passenger compartment were 4.8 G's lateral (average of 2 data channels) and less than 1 G longitudinal (average of 3 data channels). These vehicular decelerations did not exceed the tolerance levels, as defined in Appendix A, for a lap belted occupant. Thus, a lap belt restrained occupant would have sustained little or no injuries. The maximum 50 ms dummy decelerations measured were 6.5 G's lateral and 2.3 G's longitudinal. See the following page for additional test data, information, and photographs.

FIGURE 14

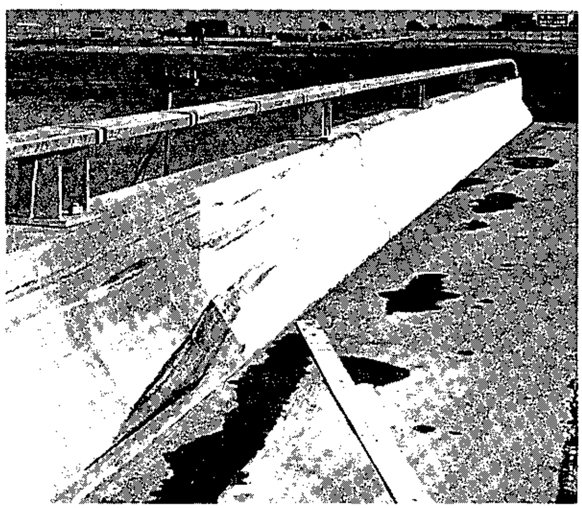
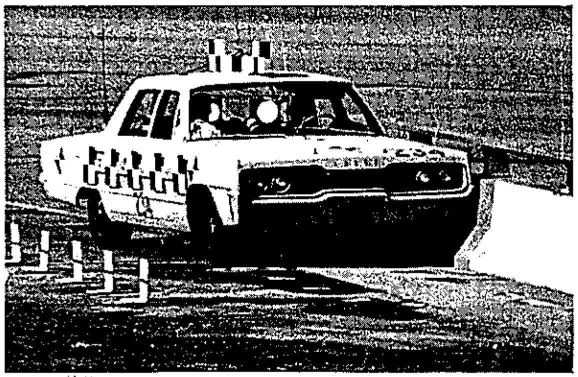
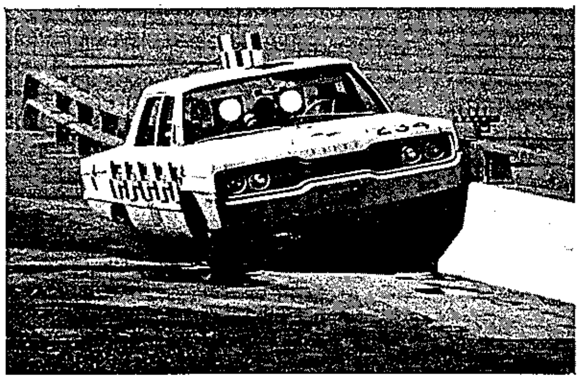


FIGURE 15

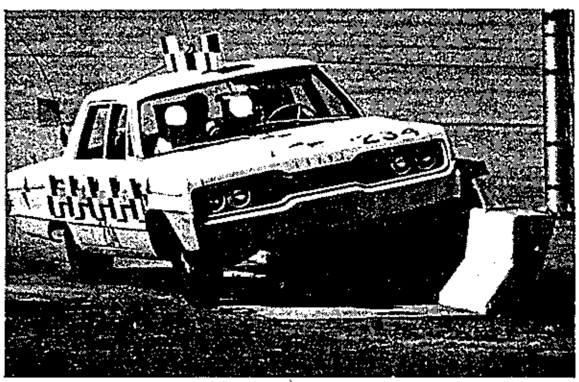
TEST 234



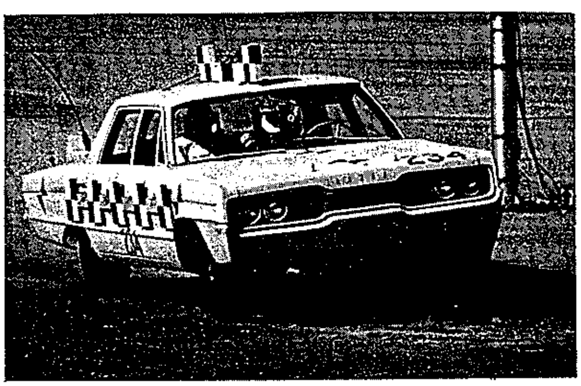
Impact + 0.01 Sec.



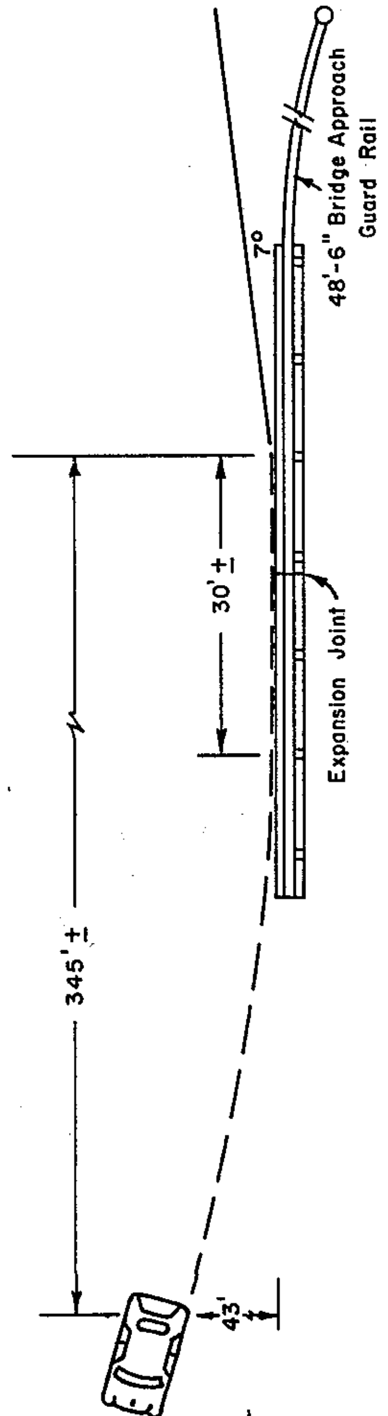
I + 0.19 Sec.

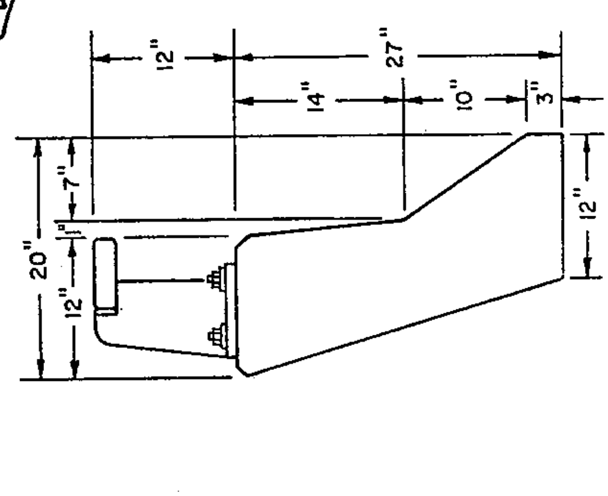


I + 0.42 Sec.



I + 0.51 Sec.





TEST NO.	234
DATE	10-29-69
VEHICLE	1966 Dodge Sedan
SPEED	64 mph
IMPACT ANGLE	7°
VEHICLE WEIGHT (Incl./dummys & instrumentation)	4980 Lbs
DUMMY RESTRAINT	Lap Belt
BARRIER TESTED	Type 20 Bridge Rail
LENGTH OF INSTALLATION	67'±
PASSENGER COMPARTMENT DECEL. (Highest 50 ms average) Long.	*
Lat.	4.8G's
MAXIMUM VEHICLE RISE	18"
EXIT ANGLE	1°
BARRIER DAMAGE	Negligible

*LESS THAN 1 G

Test No. 235

This test, the most severe impact into the barrier, was conducted using the same vehicle used for Test No. 234. The test vehicle struck the barrier 27.5 feet from the upstream end at 66 mph and at an angle of 25 degrees. After impact, the vehicle remained in contact with the barrier for approximately 12 feet before leaving the barrier at a 3 degree angle. Vehicular raise was minimal as the steel rail restricted the vehicle's tendency to ride up on the barrier parapet. This was also observed in Test 233 (15^{o} impact angle) but was not observed during Tests 231, 232, and 234 (7^{o} impact angle) as minimal vehicle-to-rail (steel) contact occurred at the shallower impact angle.

Spalling of the concrete in the vicinity of impact and a slight permanent deflection (0.1 ft.) of the steel railing indicated the severity of the impact (see Figure 16 below). The concrete portion of the barrier railing sustained a vertical crack approximately 1/16-inch wide that extended from the deck to the top of the parapet. This crack was at a point just upstream from impact. Displacement of the concrete parapet was approximately 1/8-inch at the top of the expansion joint.

As could be expected with any 25 degree impact into a rigid barrier, vehicular damage was severe (see Figure 17 below).

The maximum 50 ms decelerations measured on the floor of the vehicular passenger compartment were 9.1 G's lateral (average of two accelerometers) and 14.8 G's longitudinal (average of four accelerometers). This laterial deceleration exceeds the tolerance levels, as defined in Appendix A, for a lap-belted occupant. Thus, an occupant restrained by a lap belt would have sustained moderate to severe injuries. Both values, however, are below the tolerance level of an occupant restrained by both a lap belt and a shoulder harness and indicate that a fully restrained occupant would sustain no more than moderate injury. The maximum 50 ms average decelerations measured in the dummy driver's chest cavity were 9.2 G's longitudinal and 16.9 G's lateral. See the following page for additional test data, information, and photographs.

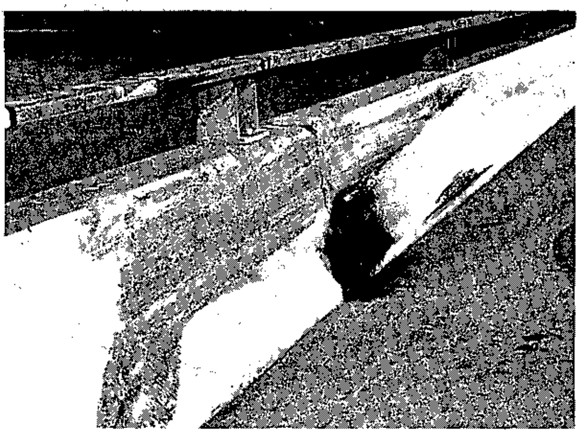


FIGURE 16

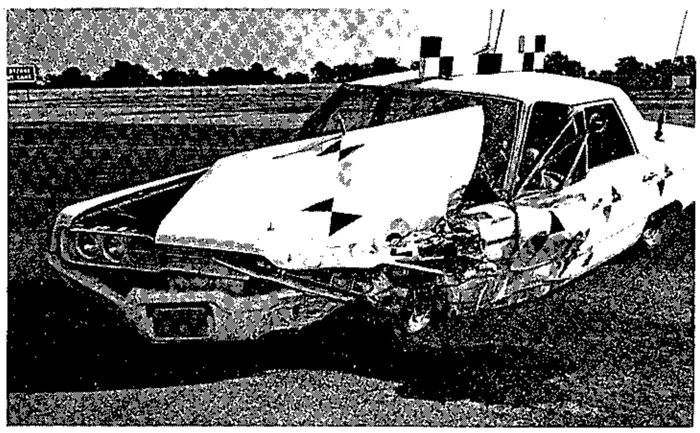
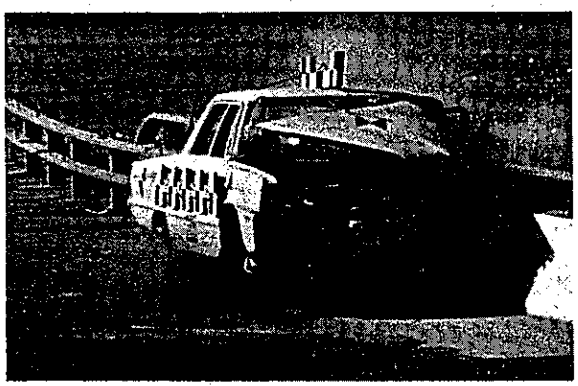


FIGURE 17

TEST 235

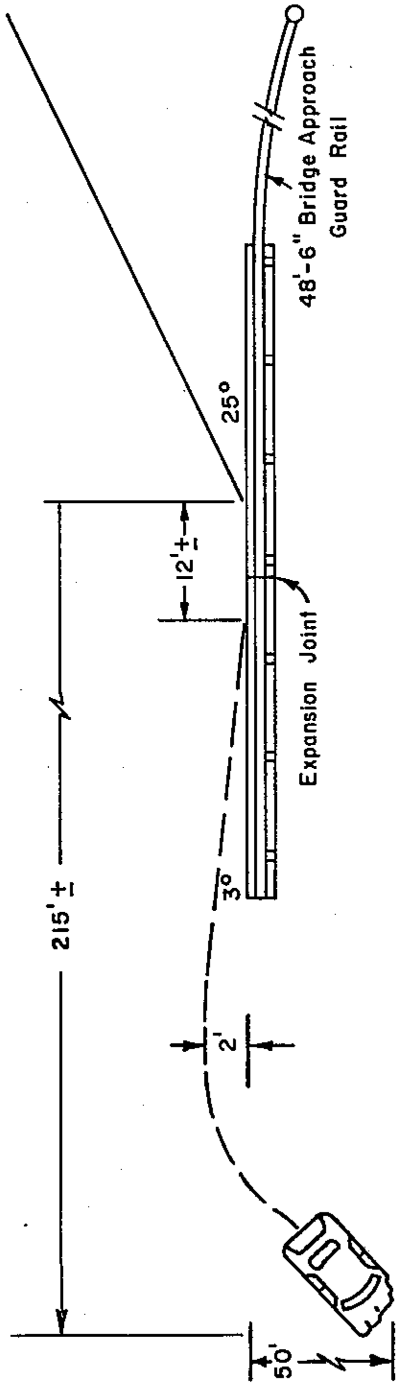
Impact +0.01 Sec.

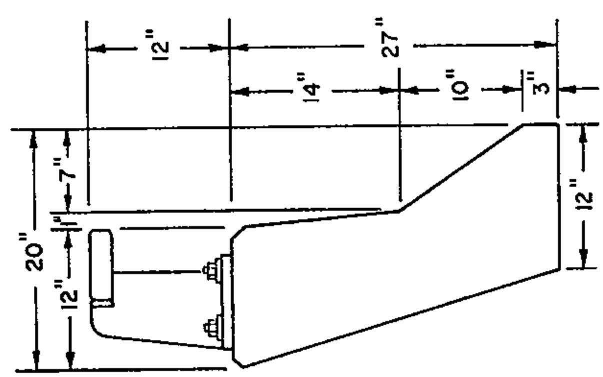
I +0.10 Sec.



I +0.28 Sec.

I +0.79 Sec.





TEST NO.	235
DATE	10-29-69
VEHICLE	1966 Dodge Sedan
SPEED	66 mph
IMPACT ANGLE	25°
VEHICLE WEIGHT (Incl./dummys & instrumentation)	4900 Lbs†
DUMMY RESTRAINT	Lap belt
BARRIER TESTED	Type 20 Bridge Rail
LENGTH OF INSTALLATION	67'±
PASSENGER COMPARTMENT DECEL. (Highest 50 ms average)	Long. 14.8 G's Lat. 9.1 G's
MAXIMUM VEHICLE RISE	Negligible
EXIT ANGLE	3°
BARRIER DAMAGE	Minor

† VEHICLE GAS TANK REMOVED

Discussion and Implementation

The results of these tests indicated that the effectiveness of sloping the traffic side of the barrier parapet diminished as the angle of impact increased. This is not surprising in that the point of initial vehicle-barrier contact shifts from the tire sidewall at a 7 degree impact angle (see Figure 18, below) to the body sheet metal at a 15 degree impact angle (see Figure 19, below).

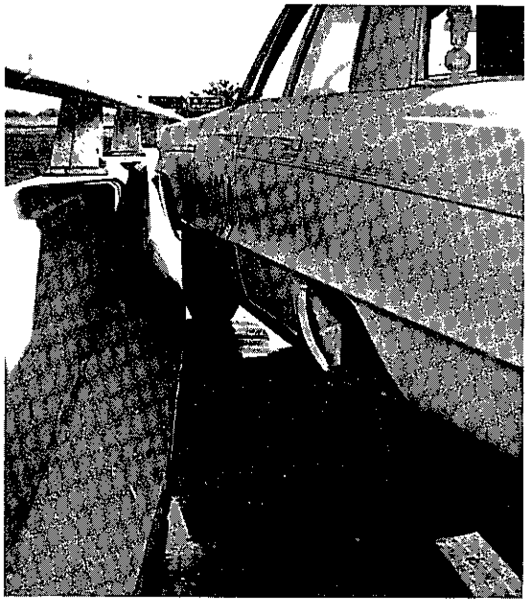


FIGURE 18

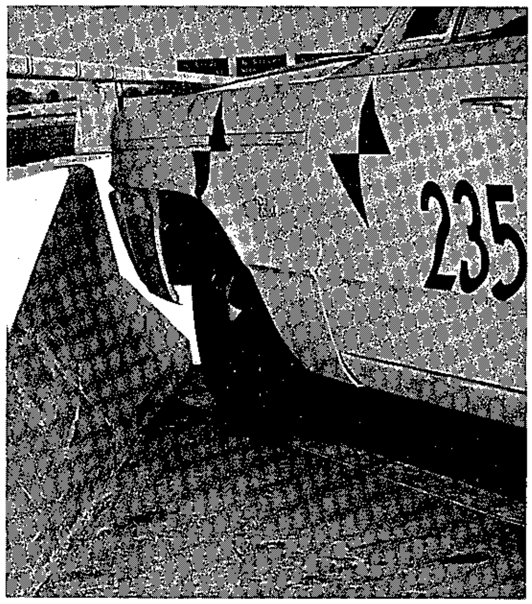


FIGURE 19

Thus, at the greater angle, a smaller proportion of the vehicle's kinetic energy is absorbed within the vehicular suspension system and a proportionally greater amount is absorbed by deformation of the vehicle's body and chassis, thus resulting in increased vehicle damage and passenger compartment decelerations. As the impact angle approaches 25 degrees, the vehicular damage sustained approaches that sustained when impacting the vertical faced Type 1 bridge barrier rail. However, an excerpt in a recent study reported in Highway Research Board Special Report 107 indicates that approximately 75% of the vehicles departing from the traveled way do so at an angle of 15 degrees or less. Almost 60% depart at 10 degrees or less, thus indicating that in a majority of the collisions that will probably occur with the Type 20 barrier, the sloped parapet face will be beneficial.

Implementation of the findings reported herein is already underway as a total of approximately 270,000 lineal feet of the California Type 20 bridge barrier rail is being included on the plans for two freeway projects in southern California. Approximately 240,000 lineal feet is planned on the new Century Freeway in the Los Angeles area and approximately 30,000 lineal feet is planned for Interstate Route 15 in the San Diego area.

VI. REFERENCES

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3. Nordlin, E. F., Field, R. N., and Stoker, J. R., "Dynamic Full Scale Impact Tests of Steel Bridge Barrier Rails, Series XI", California Division of Highways, June 1967.

4. Nordlin, E. F., Ames, W. H., and Hackett, R. P., "Dynamic Tests of Type 9 Bridge Barrier Rail and Type 8 Bridge Approach Guardrail, Series XVII", California Division of Highways, June 1969.

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13. Warner, Charles Y., "Engineering Evaluation of Water-Filled Plastic Cells in Fixed Barrier Automobile Impacts", Report No. RSCB-2, Department of Mechanical Engineering, Brigham Young University, January 5, 1968.

14. Michie, J. D., Calcote, L. R., and Bronstad, M. E., "Guardrail Performance and Design", NCHRP Final Report, Project 15-1(2), January 1970.

Exhibit 1

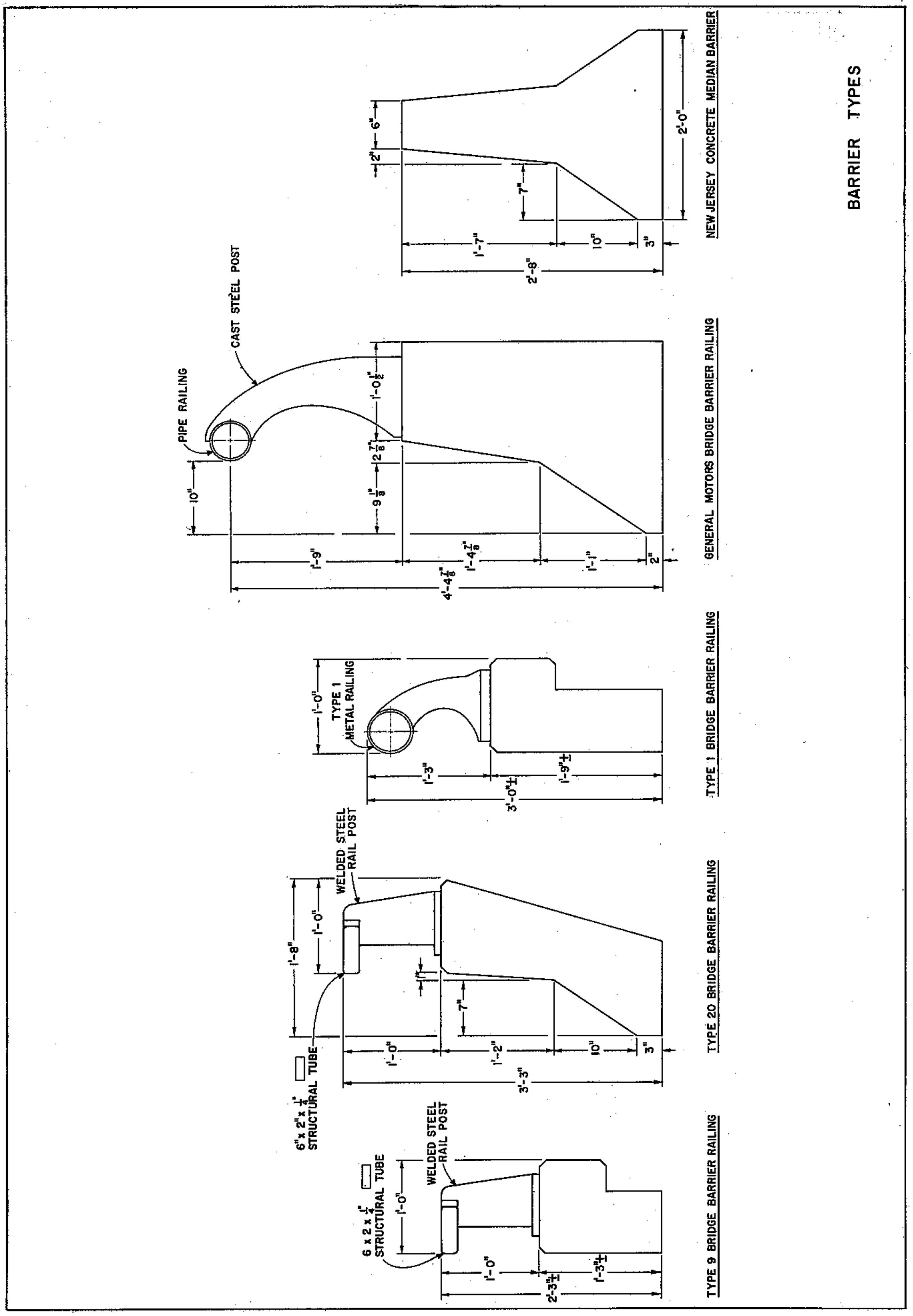
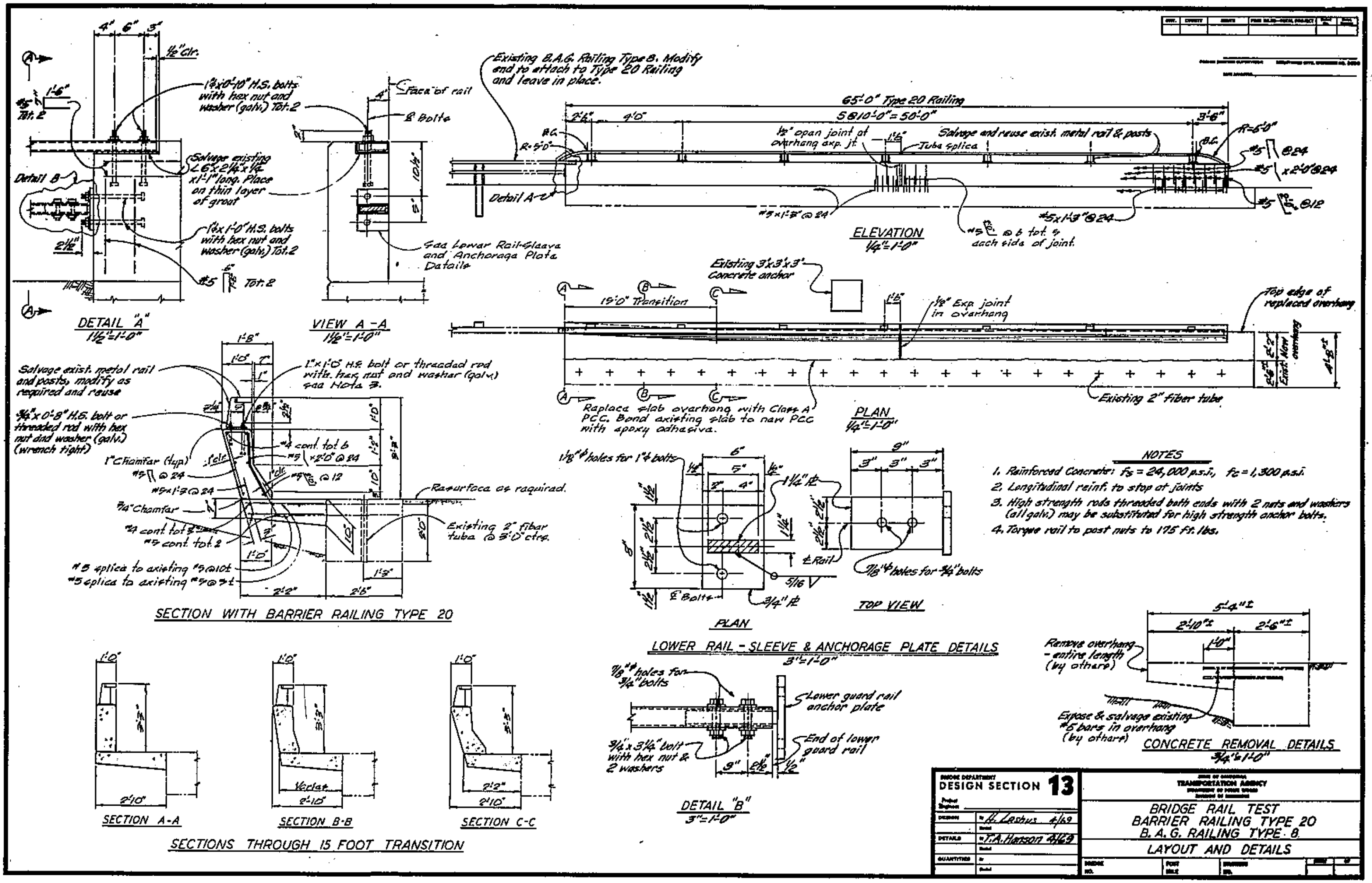

BARRIER TYPES
NEW JERSEY CONCRETE MEDIAN BARRIER
GENERAL MOTORS BRIDGE BARRIER RAILING
CAST STEEL POST
PIPE RAILING
TYPE 1 BRIDGE BARRIER RAILING
TYPE 1 METAL RAILING
TYPE 20 BRIDGE BARRIER RAILING
WELDED STEEL RAIL POST
6" x 2" x 1/4" STRUCTURAL TUBE
TYPE 9 BRIDGE BARRIER RAILING
WELDED STEEL RAIL POST
6 x 2 x 1/4" STRUCTURAL TUBE

Exhibit 2



DETAIL "A"
1½"=1'-0"
VIEW A-A
1½"=1'-0"
ELEVATION
¼"=1'-0"
65'-0" Type 20 Railing
5@10'-0"=50'-0"
Existing B.A.G. Railing Type 8. Modify end to attach to Type 20 Railing and leave in place.
Salvage and reuse exist. metal rail & posts
½" open joint at overhang exp. jt.
Tube splice
Existing 3'x3'x3' Concrete anchor
15'-0" Transition
½" Exp. joint in overhang
Top edge of replaced overhang
Replace slab overhang with Class A PCC. Bond existing slab to new PCC with epoxy adhesive.
Existing 2" fiber tube
PLAN
¼"=1'-0"
Salvage exist. metal rail and posts, modify as required and reuse
1"x1'-0" H.S. bolt or threaded rod with hex nut and washer (galv.) See Note 3.
¾"x0'-8" H.S. bolt or threaded rod with hex nut and washer (galv.) (wrench tight)
Resurface as required.
Existing 2" fiber tube @ 3'-0" ctrs.
#5 splice to existing #5@10t
#5 splice to existing #5@9t
SECTION WITH BARRIER RAILING TYPE 20
NOTES
1. Reinforced Concrete: fs = 24,000 p.s.i., fc = 1,300 p.s.i.
2. Longitudinal reinf. to stop at joints
3. High strength rods threaded both ends with 2 nuts and washers (all galv.) may be substituted for high strength anchor bolts.
4. Torque rail to post nuts to 175 ft. lbs.
1⅛" holes for 1¼" bolts
13/16" holes for ¾" bolts
PLAN
TOP VIEW
LOWER RAIL - SLEEVE & ANCHORAGE PLATE DETAILS
3"=1'-0"
Lower guard rail anchor plate
End of lower guard rail
¾"x3¼" bolt with hex nut & 2 washers
DETAIL "B"
3"=1'-0"
Remove overhang - entire length (by others)
Expose & salvage existing #5 bars in overhang (by others)
CONCRETE REMOVAL DETAILS
¾"=1'-0"
SECTION A-A
SECTION B-B
SECTION C-C
SECTIONS THROUGH 15 FOOT TRANSITION
DESIGN SECTION 13
H. Loshus 4/69
T.A. Hanson 4/69
TRANSPORTATION AGENCY
BRIDGE RAIL TEST
BARRIER RAILING TYPE 20
B. A. G. RAILING TYPE 8
LAYOUT AND DETAILS

APPENDIX A

Data Processing and Interpretation

I. Introduction

The accelerometer records for Tests 231 and 233 were not analyzed. In Test 231 the amplitudes of the accelerometer traces were small compared to the electronic interference ("noise") which was recorded, thus making it impossible to interpret the data. In Test 233, the results were obviously incorrect due to a malfunction in the instrumentation system.

Fairly good results were obtained from the other three tests. Data from Tests 232 and 234 are discussed together since both tests involved a vehicle with a speed of about 65 mph and an impact angle of 7 degrees.

II. Filtering

The unfiltered accelerometer data included numerous groups of unusually high, thin spikes, indicating a "ringing" in the accelerometer. This ringing was most prevalent with the FM Telemetry transmission of data. These spikes were often unsymmetrical about the line of zero acceleration, so during the integration process of filtering, high narrow peaks were formed which did not represent over-all vehicle behavior. In some instances, it was difficult to tell whether this peak was or was not superimposed on the true acceleration peaks. Also, the identification of "noise" on the filtered data was impossible without making reference to the raw data to locate the time at which the very high frequency spikes were recorded. The exact cause of the ringing was never established; it may have been caused by high frequency vibrations in the car body or interference of the radio waves generated by the telemetry system transmitters in the test vehicle.

The choice of 100 Hz as the electronic filtering rate was based on a visual comparison of the original data and the same data filtered at several frequencies between 100 Hz and 20 Hz. The use of this filtered data greatly facilitated visual interpretation of the accelerometer records. See Plate 1 for an example of the effect of this electronic filtering.

In addition to electronic filtering, "manual" filtering of the accelerometer data is accomplished, to some extent, when the time intervals over which the maximum peak decelerations and highest average decelerations are chosen. The effect of this interval is dependent on the nature of the original and/or filtered data, whichever is being interpreted. This can be seen by examining Table I, A-3. The values were chosen by calculating the areas under the curves at five milliseconds (ms) intervals and then combining to determine the maximums. There is only a 10.5% drop in the deceleration reading for Test 235, Channel 3, when the time interval is increased from 10 ms to 50 ms whereas a 56.5% drop occurred for Test 235, Channel 6.

In all cases, the time interval for the highest 10 ms and 25 ms average decelerations were within the highest 50 ms average deceleration time period.

III. <u>Deceleration Data</u>

The deceleration records for Tests 232, 234, and 235 are included as Plates 2 through 21 of this Appendix. In all cases, the filtration rate was 100 Hz.

Tests 232 and 234:

A comparison of the vehicular lateral decelerations for Tests 232 and 234 (Plates 2-5) shows them to be somewhat similar except that in Test 234 the actual short-time peak value varies slightly. In Channel 5 (Plate 5) this may have been due to interference superimposed on the main peak as this channel showed several other peaks which were judged to be interference of some type. These interference peaks can often be identified on the unfiltered traces as long thin spikes of about one millisecond duration that occur in the middle of oscillating peaks of much lower frequency and amplitude.

Results from Channel 9 (Plate 3) were a bit surprising since the accelerometer was calibrated to give very low amplitude traces, yet the basic shape and the peak value agree well with the other records.

Observations of and computations from the movies showed the time when the back of the car slapped the barrier to be approximately impact + 150 ms. This time corresponds to the time of the main lateral peaks on the accelerometer records. There are no definite peaks on these records of lateral deceleration when the front of the car strikes the barrier.

It appears that the main lateral deceleration peak in Test 232 lagged the main peak in Test 234 by about 20-30 ms. This agreement is surprisingly good considering that it is nearly impossible to determine from the movies the exact time at which the wheel and/or bumper first contacts the barrier. Therefore, variations in the selection of the instant of impact among different researchers could be as much as 10 or 15 ms within any single test.

TABLE I

DEPENDENCY OF "PEAK" DECELERATION MAGNITUDE ON TIME INTERVAL

Test Number	Channel	Location	Orientation	Maximum Average Deceleration (G's) 10 ms	25 ms	50 ms	Transmission
232 (7°/66 mph)	4	Vehicle-E	Lateral	10.9	8.3	4.8	Telemetry
	9	Vehicle-E	Lateral	10.6	8.3	4.7	Hardwire
	6	Dummy	Lateral	8.4	7.2	6.1	Telemetry
	7	Dummy	Vertical	5.9	2.8	2.2	Telemetry
234 (7°/64 mph)	2	Vehicle-A	Lateral	9.2	7.8	4.3	Telemetry
	5	Vehicle-E	Lateral	11.5	8.5	5.2	Telemetry
	1	Vehicle-A	Longitudinal	1.6	1.2	-	Telemetry
	3	Vehicle-E	Longitudinal	2.3	1.8	-	Telemetry
	4	Vehicle-E	Longitudinal	2.3	2.0	-	Telemetry
	6	Dummy	Lateral	11.2	9.8	6.5	Telemetry
	7	Dummy	Longitudinal	3.4	3.2	2.3	Telemetry
235 (25°/66 mph)	2	Vehicle-A	Lateral	25.6	24.7	20.7	Telemetry
	5	Vehicle-E	Lateral	11.0	9.7	8.7	Telemetry
	9	Vehicle-E	Lateral	11.8	10.4	9.5	Hardwire
	1	Vehicle-A	Longitudinal	22.0	16.0	14.3	Telemetry
	3	Vehicle-E	Longitudinal	21.9	20.0	19.6	Telemetry
	4	Vehicle-E	Longitudinal	14.3	13.6	12.6	Telemetry
	8	Vehicle-E	Longitudinal	15.0	13.8	12.7	Hardwire
	6	Dummy	Lateral	38.8	27.8	16.9	Telemetry
	7	Dummy	Longitudinal	14.8	11.1	9.2	Telemetry

None of the accelerometers oriented longitudinally in Test 232 produced usable records. The longitudinal records for Test 234 (Plates 6-8) had a number of spikes which appeared to be interference of some type. If these spikes are overlooked, the traces obtained with the three channels are all quite similar.

The longitudinal backslap peaks, which occurred about 30 ms before the lateral backslap peaks, were opposite in direction to the initial peaks. This suggests that the backslap contributes to vehicle acceleration in the longitudinal direction while decelerating it in the lateral direction, like a stone skipping on water. This lateral and longitudinal deceleration data also indicate that, for shallow angle impacts such as these (7 degree impact angle), the backslap produces the most severe vehicular deceleration.

The maximum 50 ms average lateral deceleration sustained by the dummy during these two tests (6.1 G's - 232, 6.5 G's - 234) agreed quite well. The general shape of both dummy lateral deceleration records, Plates 9-12, was somewhat similar and the lateral 50 ms average maximum deceleration was greater than the vertical (232) and longitudinal (234) 50 ms maximums in both cases. These 50 ms peak lateral decelerations occurred 30-40 milliseconds after the vehicle lateral peaks. Both lateral traces and the longitudinal trace showed twin peaks separated by a thin sharp dip -- as if the dummy bounced quickly at the time of maximum deceleration. This double peak was also on the unfiltered traces. The values of 2.2 G's vertical and 2.3 G's longitudinal indicate that, although the lateral deceleration is the greatest, both longitudinal and vertical decelerations could be significant for unrestrained occupants even in 7 degree impacts.

Test 235:

The average 50 ms maximum average vehicular decelerations were 9.1 G's lateral (average of Channels 5 and 9, Plates 14 and 15) and 14.8 G's longitudinal (average of Channels 1, 3, 4, and 8, Plates 16-19). The maximum lateral deceleration occurred during the backslap but was of the same order of magnitude as the lateral deceleration that occurred at the time of maximum 50 ms vehicular longitudinal deceleration.

Channels 5 and 9 (Plates 14 and 15) are very similar. There was only one questionable high spike on Channel 5. Channel 2 (Plate 13) has a trace very similar to those for Channels 5 and 9 except that the peak values for Channel 2 are much higher. Even though position A (see page 11) is closer to the front of the vehicle then position E, the Channel 2 trace should be similar to those of Channels 5 and 9 because all the significant vehicular deformation took place forward of position A. A possible reason for the Channel 2 trace being similar but of higher magnitude than Channels 5 and 9 is a calibration error. Another possibility could be the relative proximity of locations A and E to the center of rotation of the car about a vertical axis (i.e., tangential accelerations and velocities may be significant). However, the significantly higher 50 ms peak longitudinal deceleration recorded at position E (Channel 3) contradicts this explanation. In any case, the values from Channel 2 were considered questionable.

It was difficult to isolate "interference" spikes on the unfiltered traces of Channels 2, 5, and 9'; it appears that some of the high narrow peaks at the time of first impact are interference superimposed on the main deceleration pulse.

Channels 4 and 8 (Plates 18 and 19), containing both different accelerometers and different modes of data transmission, are very similar except for a difference in the maximum value of deceleration during backslap. Channels 3 and 4 (Plates 17 and 18), containing the same accelerometer, had data transmitted on two separate channels; thus they should have identical traces. They do have similar pulse shapes; however, Channel 3 has significantly higher peak values. Because of the close agreement between Channels 4 and 8, it normally would be assumed that Channel 3 was improperly calibrated for some reason. Its peak 10 ms value does, however, agree with that recorded at the more forward location A (Channel 1). Channel 1 has a pulse shape resembling those on Channels 3, 4, and 8 but with higher peaks than Channels 4 and 8. The results for Channel 1, however, correlate with those on Channel 2 in the lateral direction at location A, in that peak values are higher than corresponding ones at location E.

In addition to the main peak values described above, there are two initial 8-10 G peaks during the first 50 ms after impact. These peaks are similar on Channels 1, 3, 4, and 8 (except that the peak values on Channel 3 are higher, which further suggests improper calibration of Channel 3), and occurred when contact with the fabricated steel post supporting the 6 inch by 2 inch railing occurred.

The maximum 50 ms deceleration for the dummy was 16.9 G's lateral (vehicle recorded 9.1 G's) and 9.2 G's longitudinal (Plates 20 and 21). However, both traces contained significant interference, thus making the separation of deceleration and noise very difficult. The time lag between vehicular peak deceleration and dummy deceleration was on the order of 30 ms, as was the case with the shallow angle impacts.

IV. Interpretation of Deceleration Measurements

The determination of deceleration tolerance limits that can be used to interpret the significance of the deceleration measurements reported herein has been somewhat unsuccessful.

The following three criteria have been reviewed with regard to this problem:

1. The tentative tolerable limits of deceleration proposed by the Cornell Aeronautical Laboratory in 1961[11] are for a duration of impact less than 200 ms and a rate of onset less than 500 G's per second. They are often applied to vehicle deceleration (not dummy decelerations) and are shown below:

Occupant Restraint	Maximum Deceleration (G's) Lateral	Longitudinal	Total
Unrestrained	3	5	6
Lap belt	5	10	12
Lap belt & shoulder harness	15	25	25

2. After making reference to the Cornell table shown in 1 above, the New York Bureau of Physical Research attempted to limit total deceleration to 10 G's for no more than 50 ms at the vehicle center of gravity during a recent test series[12].

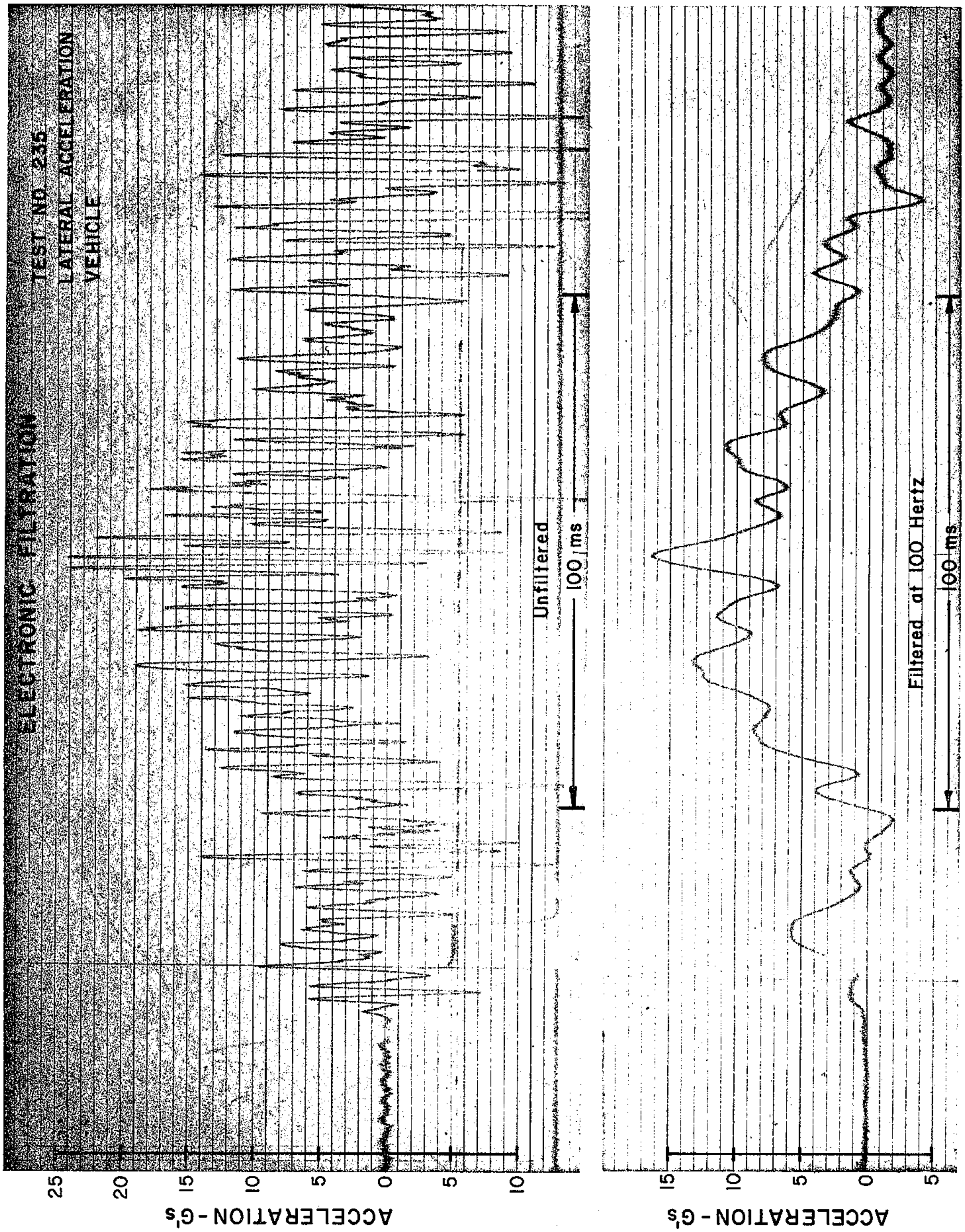
3. Bureau of Public Roads Guidelines limit the rate of onset to 500 G's/sec., the maximum 40 ms average to 12 G's, and suggest that the remainder of the deceleration be as low as possible[13].

All these criteria are applied to the vehicular deceleration. It is acknowledged, however, that the similarity of the vehicular deceleration and the occupant deceleration is dependent on the restrain system, if any, used by the vehicle occupant. The interpretation of these criteria is somewhat unclear in that no magnitude-duration limitation is specified for relatively small time periods. For example, if the average 50 ms peak was 25 G's but the 200 ms average was 10 G's, would this be tolerable for a lap belted occupant? Criteria 1 suggested it <u>would be tolerable</u>. Criterias 2 and 3 suggest it <u>would not be tolerable</u>.

The interpretation of the vehicular decelerations measured during Tests 232, 234, and 235 was accomplished using the Cornell limits but applying them to the highest 50 ms average. This decision is based on the contention that shorter duration, higher average decelerations will, in general, also be tolerable[14]. Also, the 12 G limit (Cornell) for lap belted occupants is in general agreement with criteria 2 and 3 above. The reasoning behind higher lateral deceleration tolerances if lap belts or lap belts and shoulder harnesses are used is unclear. Perhaps the structural capacity of door latches and/or the relative dangers associated with partial or complete ejection were the basis for the establishment of these tolerance levels. In any case, they have been accepted for the purpose of this study.

Applying this criteria to the vehicular decelerations measured indicates that the tolerable lateral deceleration was exceeded for an unrestrained person during all three tests. An occupant restrained by a lap belt would, however, have sustained tolerable lateral decelerations in Tests 232 and 234. For Test 235, the value for Channel 2 was ignored. The average of Channels 5 and 9 (9.1 G's) exceeded the tolerance level for lateral deceleration assuming lap belt restraint but was well within the 15 G limit if a shoulder harness were also used. The longitudinal deceleration for 234 was well within the tolerable limits for an unrestrained occupant. However, the longitudinal deceleration measured in 235 was such that both a lap belt and a shoulder harness would have been required to classify the impact as tolerable.

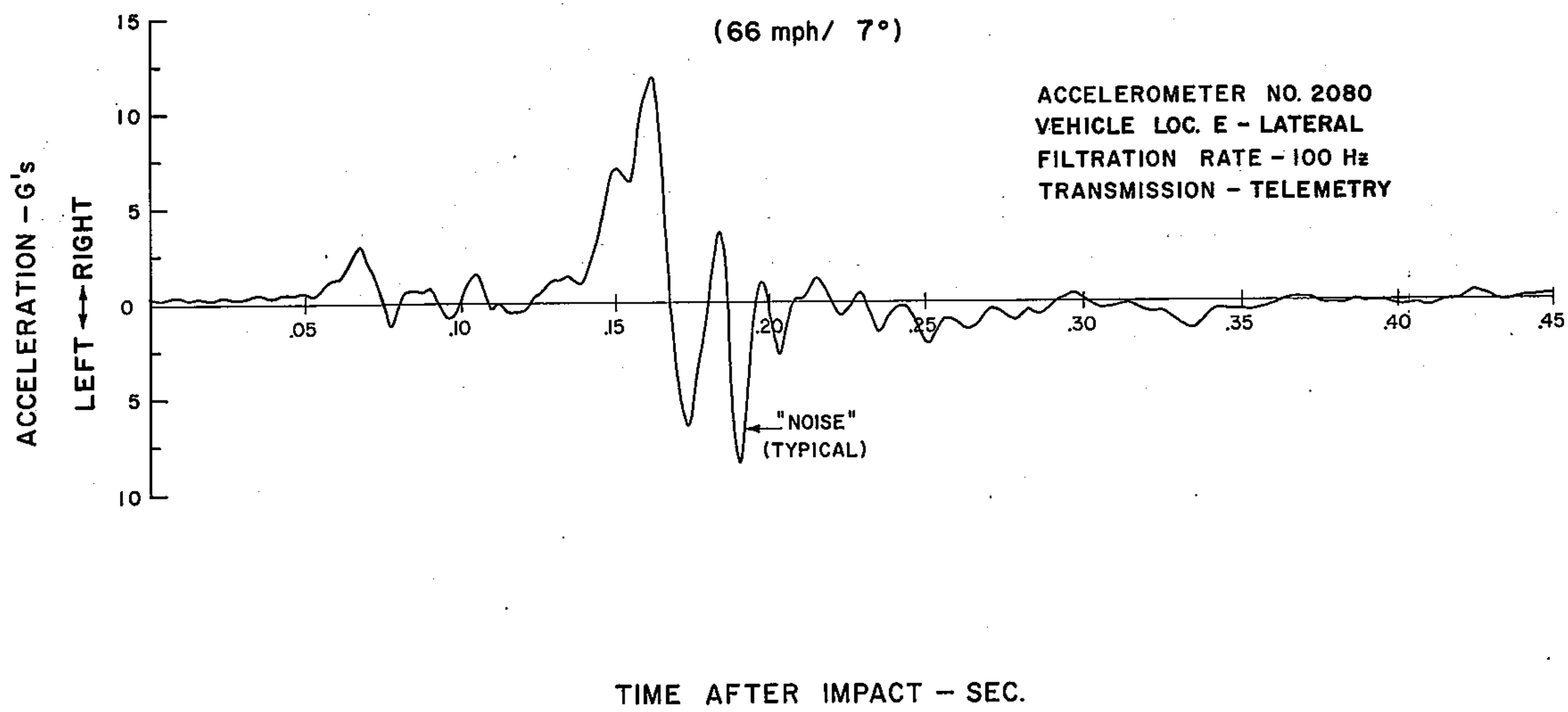
Consequently, the over-all conclusion would be that a vehicular occupant restrained by a lap belt would have sustained tolerable decelerations in both 65± mph 7 degree tests. The decelerations in Test 235 (66 mph, 25 degrees) were such that the vehicle occupants' deceleration limit would have been exceeded unless both a lap belt and shoulder harness were used. Unrestrained occupants would have probably sustained some injuries during the 7 degree tests, moderate injuries during the 15 degree test, and considerable injuries during the 25 degree test.


ELECTRONIC FILTRATION
TEST NO 235
LATERAL ACCELERATION
VEHICLE
Unfiltered
100 ms
ACCELERATION - G's
25
20
15
10
5
0
5
10
Filtered at 100 Hertz
100 ms
ACCELERATION - G's
15
10
5
0
5

ACCELERATION VS TIME

TYPE 20 BRIDGE RAIL TEST 232 CHANNEL 4

(66 mph/ 7°)

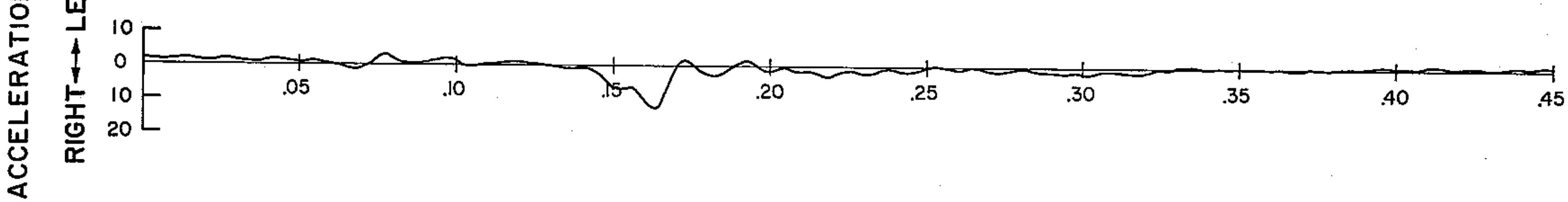


ACCELERATION VS TIME

TYPE 20 BRIDGE RAIL TEST 232 CHANNEL 9

(66 mph/ 7°)

ACCELEROMETER NO. 590
VEHICLE LOC. E – LATERAL
FILTRATION RATE – 100 Hz
TRANSMISSION – HARDWIRE



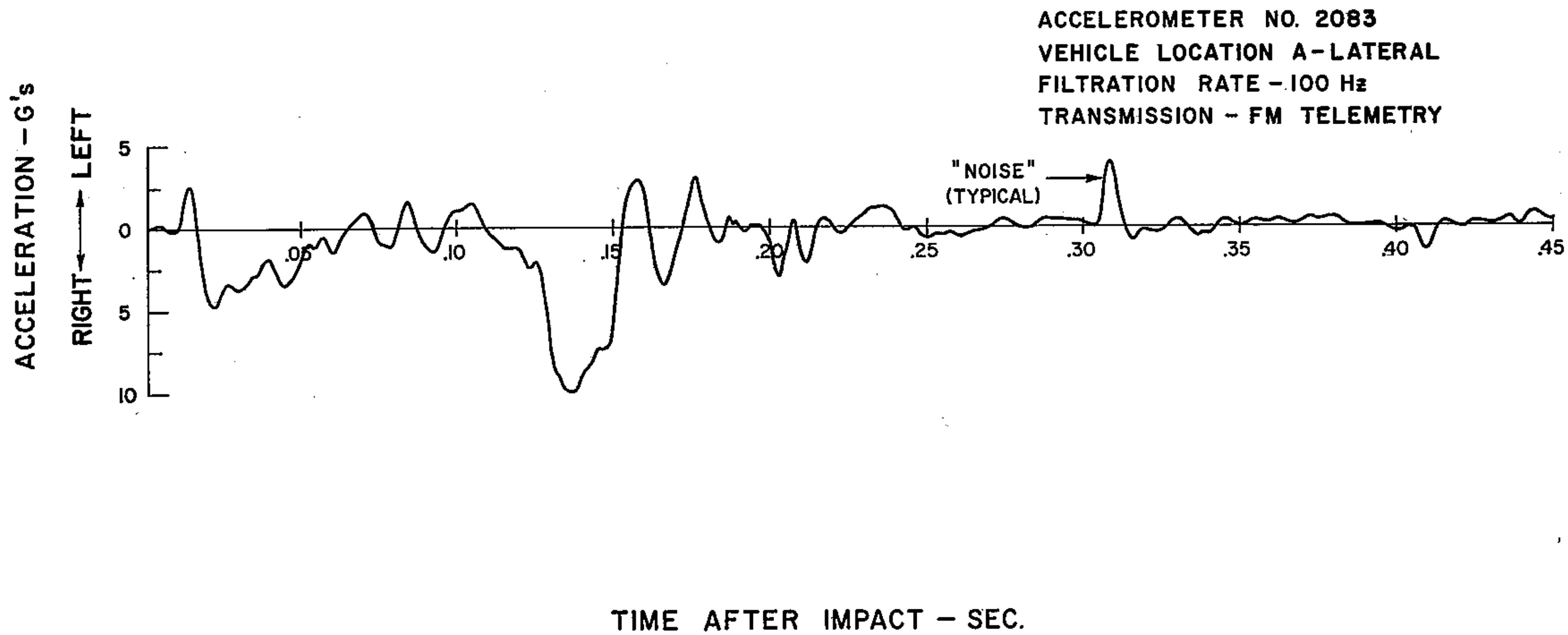
TIME AFTER IMPACT – SEC.

PLATE 4

ACCELERATION VS TIME

TYPE 20 BRIDGE RAIL TEST 234 CHANNEL 2

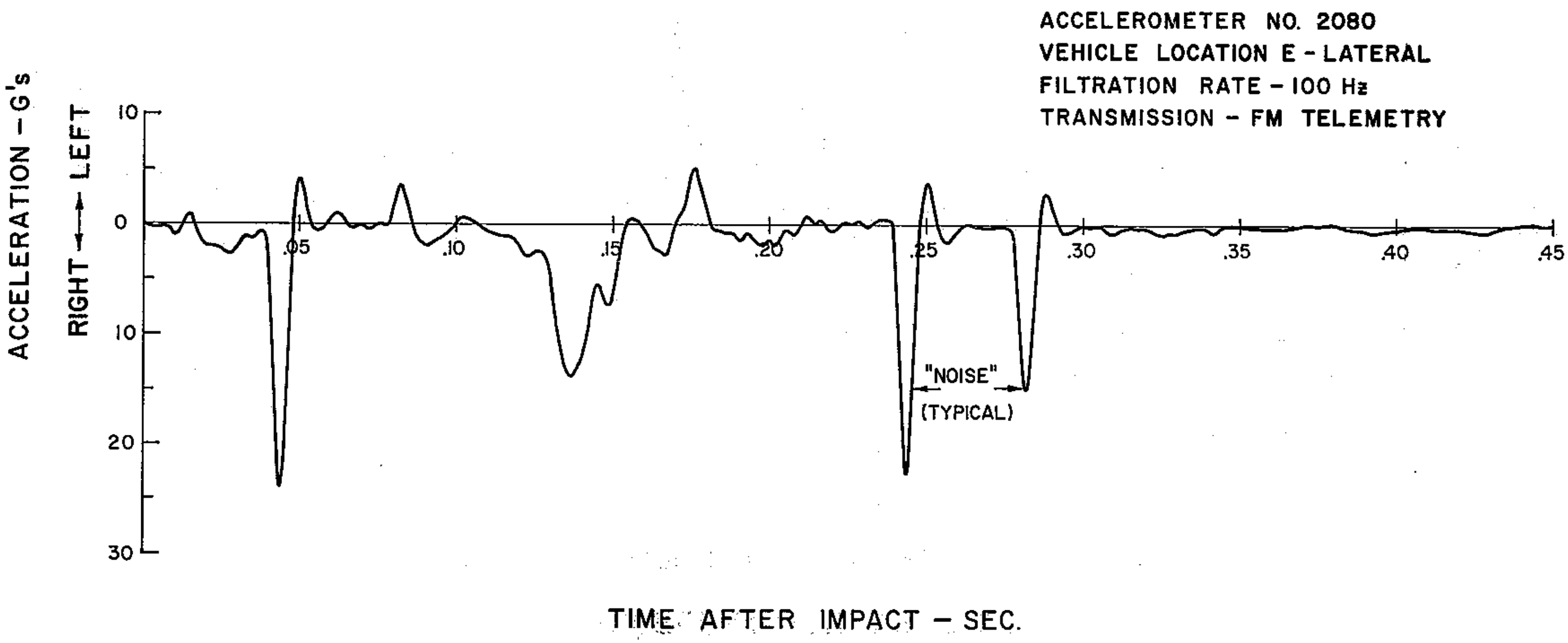
(64 mph/ 7°)



ACCELERATION VS TIME

TYPE 20 BRIDGE RAIL TEST 234 CHANNEL 5

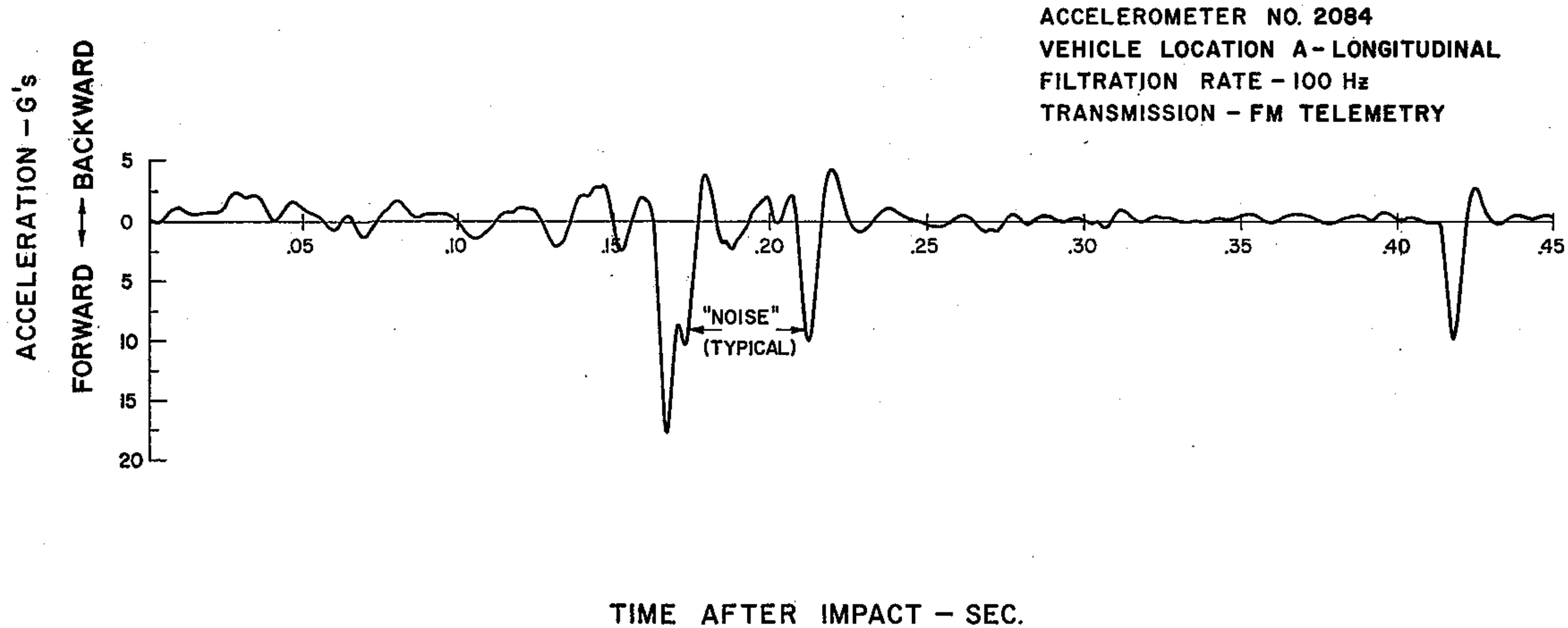
(64 mph/ 7°)



ACCELERATION VS TIME

TYPE 20 BRIDGE RAIL TEST 234 CHANNEL 1

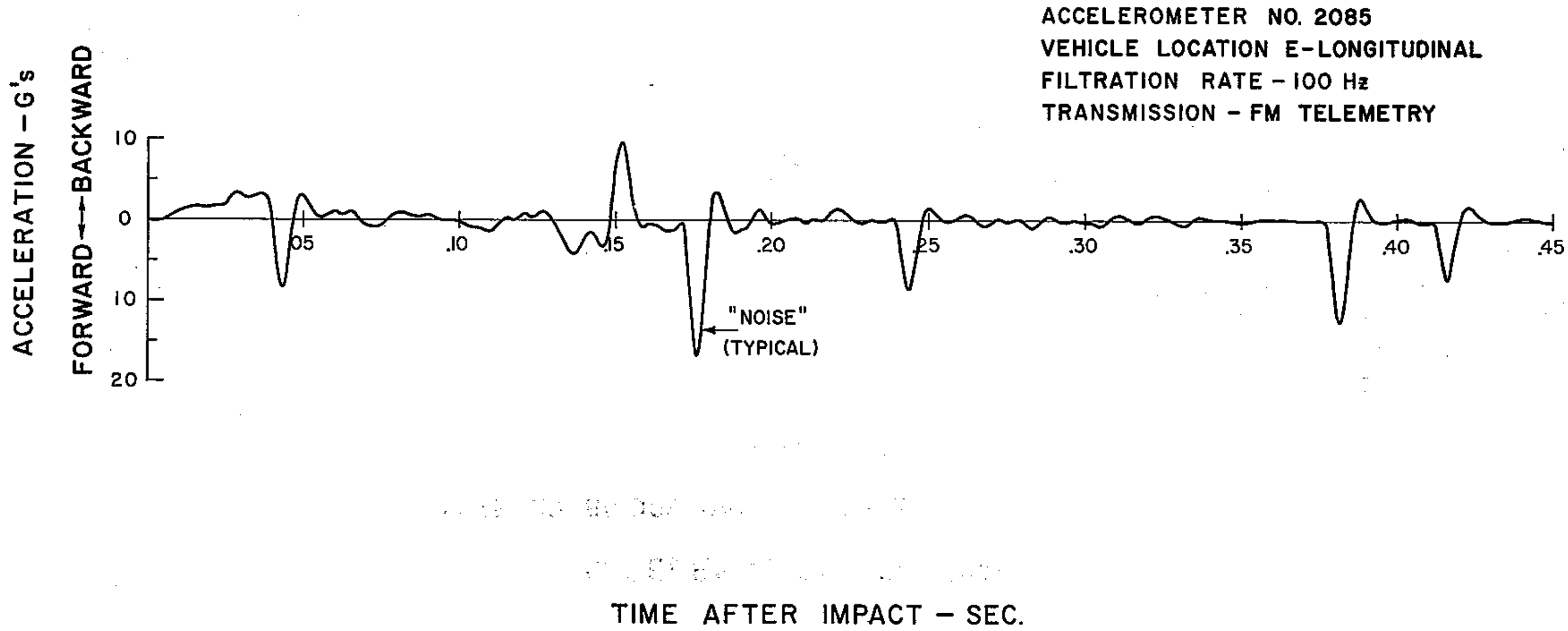
(64 mph/ 7°)



ACCELERATION VS TIME

TYPE 20 BRIDGE RAIL TEST 234 CHANNEL 3

(64 mph/ 7°)

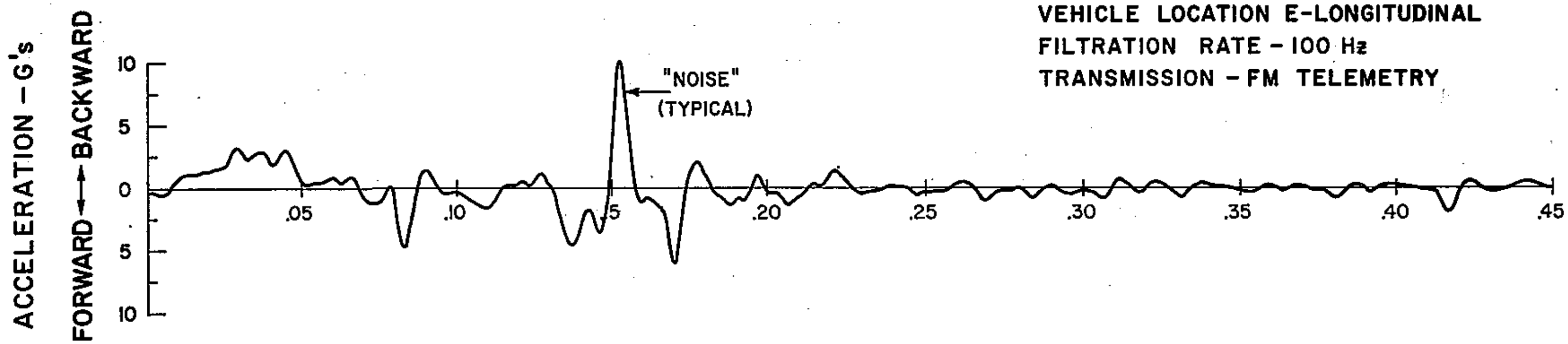


ACCELERATION VS TIME

TYPE 20 BRIDGE RAIL TEST 234 CHANNEL 4

(64 mph/ 7°)

ACCELEROMETER NO. 2085
VEHICLE LOCATION E-LONGITUDINAL
FILTRATION RATE - 100 Hz
TRANSMISSION - FM TELEMETRY



TIME AFTER IMPACT - SEC.

ACCELERATION VS TIME

TYPE 20 BRIDGE RAIL TEST 232 CHANNEL 6

(66 mph/ 7°)

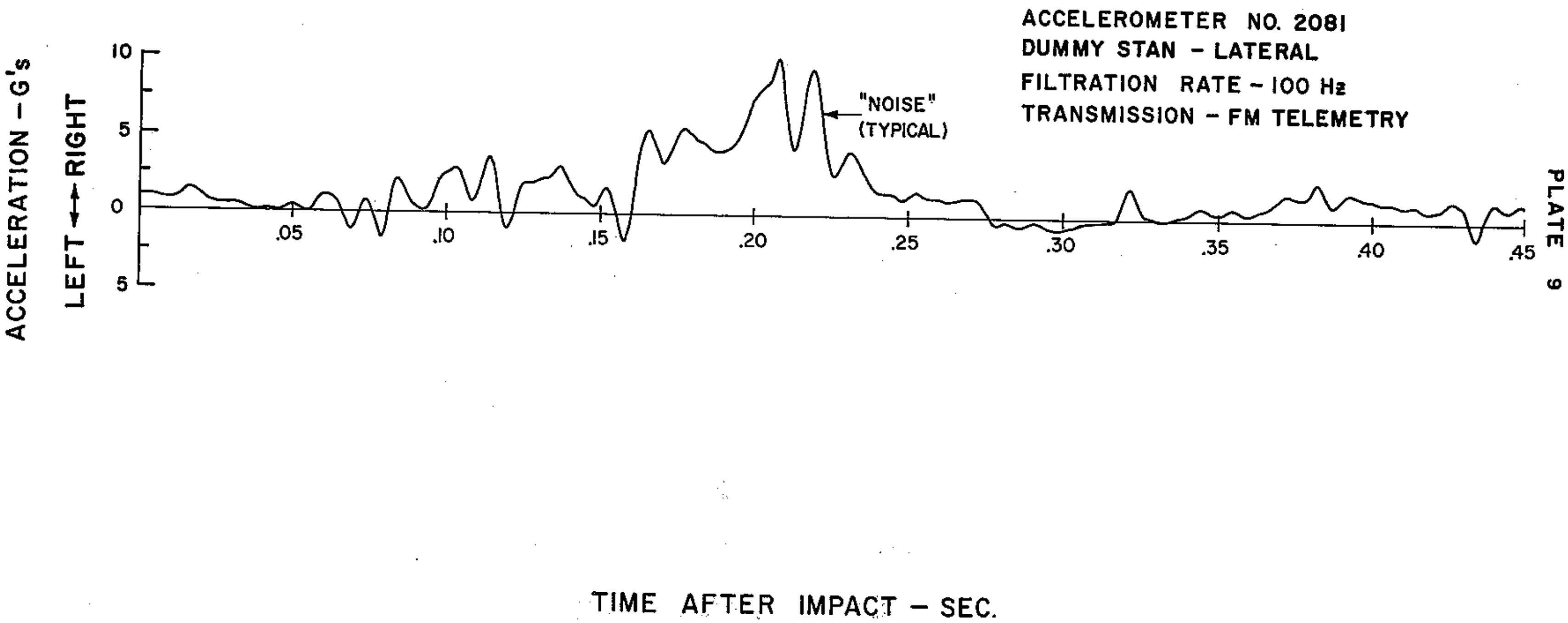
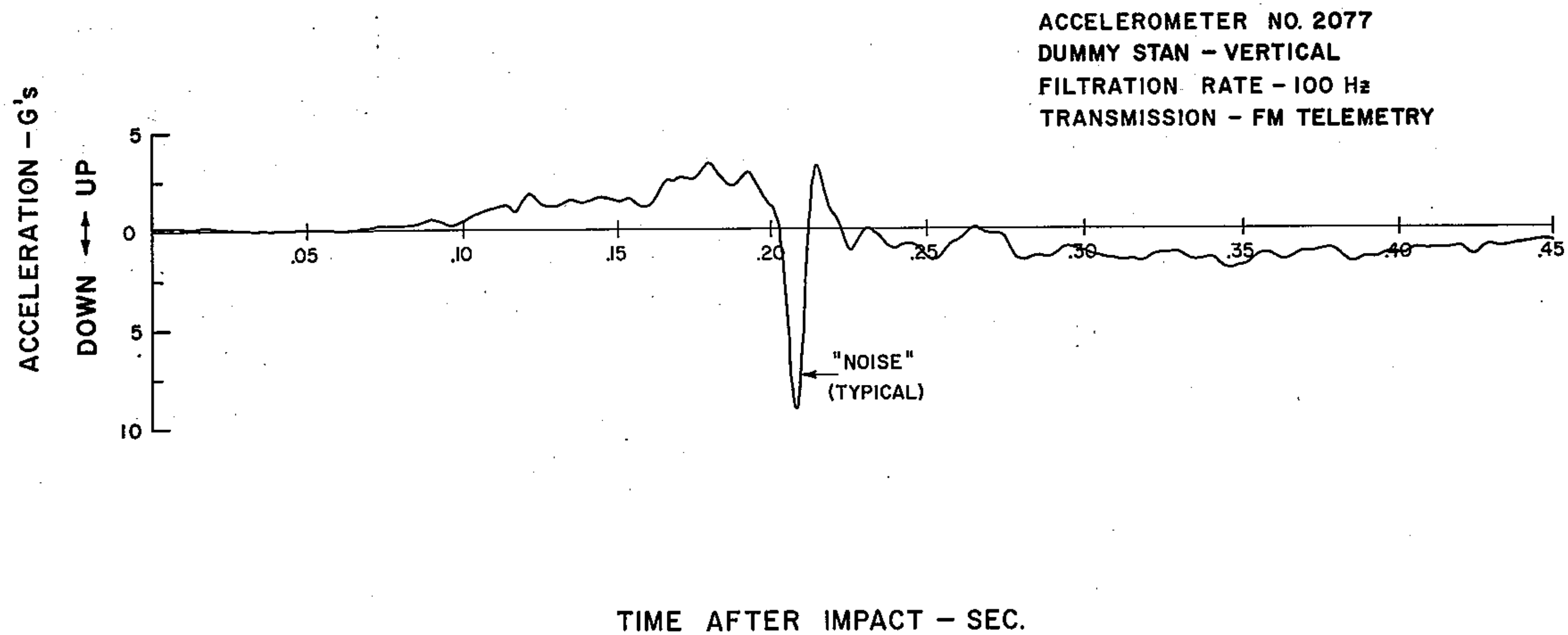


PLATE 10

ACCELERATION VS TIME

TYPE 20 BRIDGE RAIL TEST 232 CHANNEL 7

(66 mph/ 7°)



ACCELERATION VS TIME

TYPE 20 BRIDGE RAIL TEST 234 CHANNEL 6

(64 mph/ 7°)

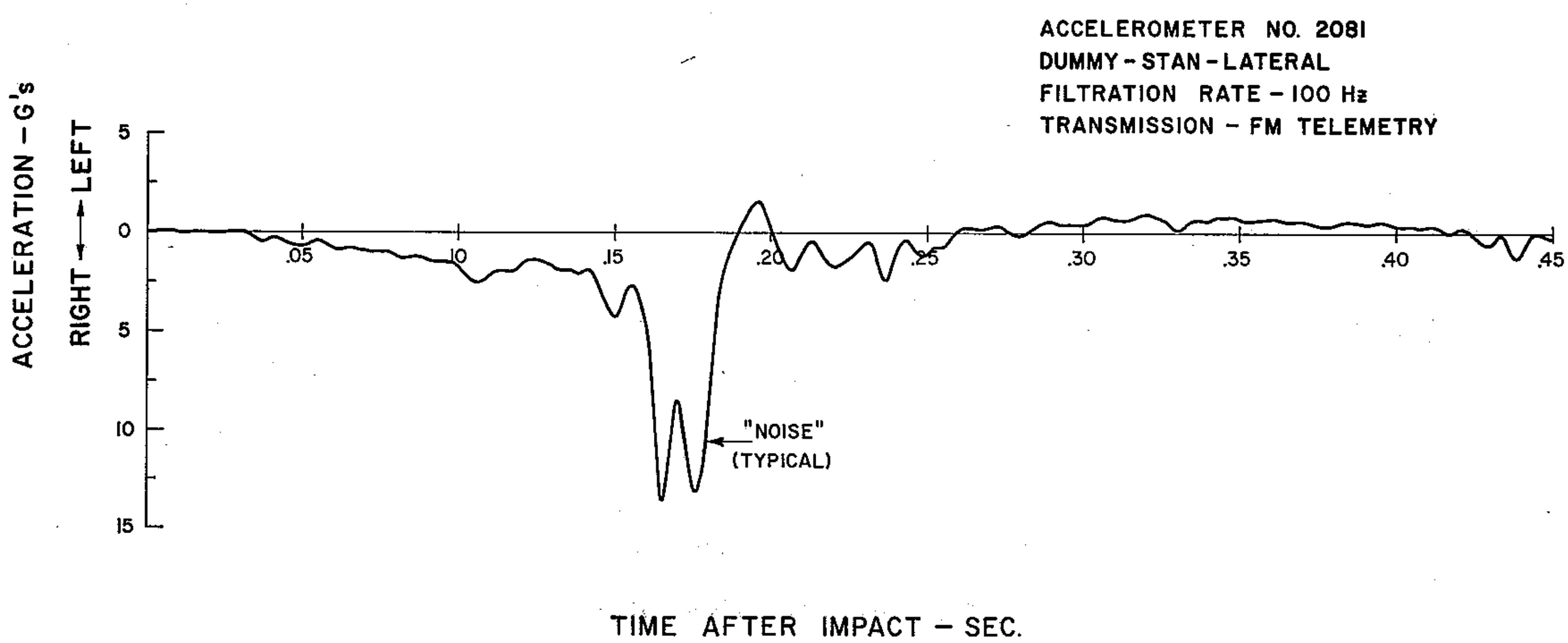
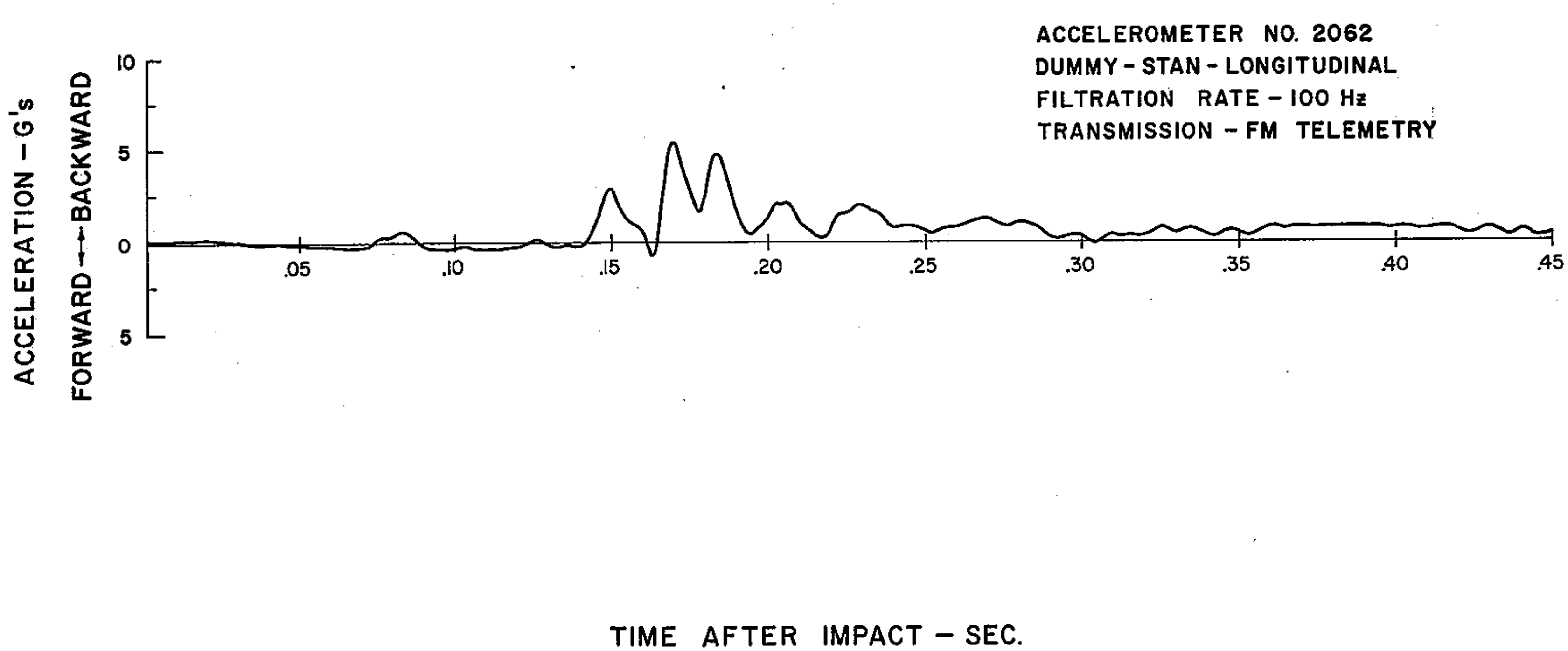


PLATE 12

ACCELERATION VS TIME

TYPE 20 BRIDGE RAIL TEST 234 CHANNEL 7

(64 mph/ 7°)



ACCELERATION VS TIME

TYPE 20 BRIDGE RAIL TEST 235 CHANNEL 2

(66 mph/ 25°)

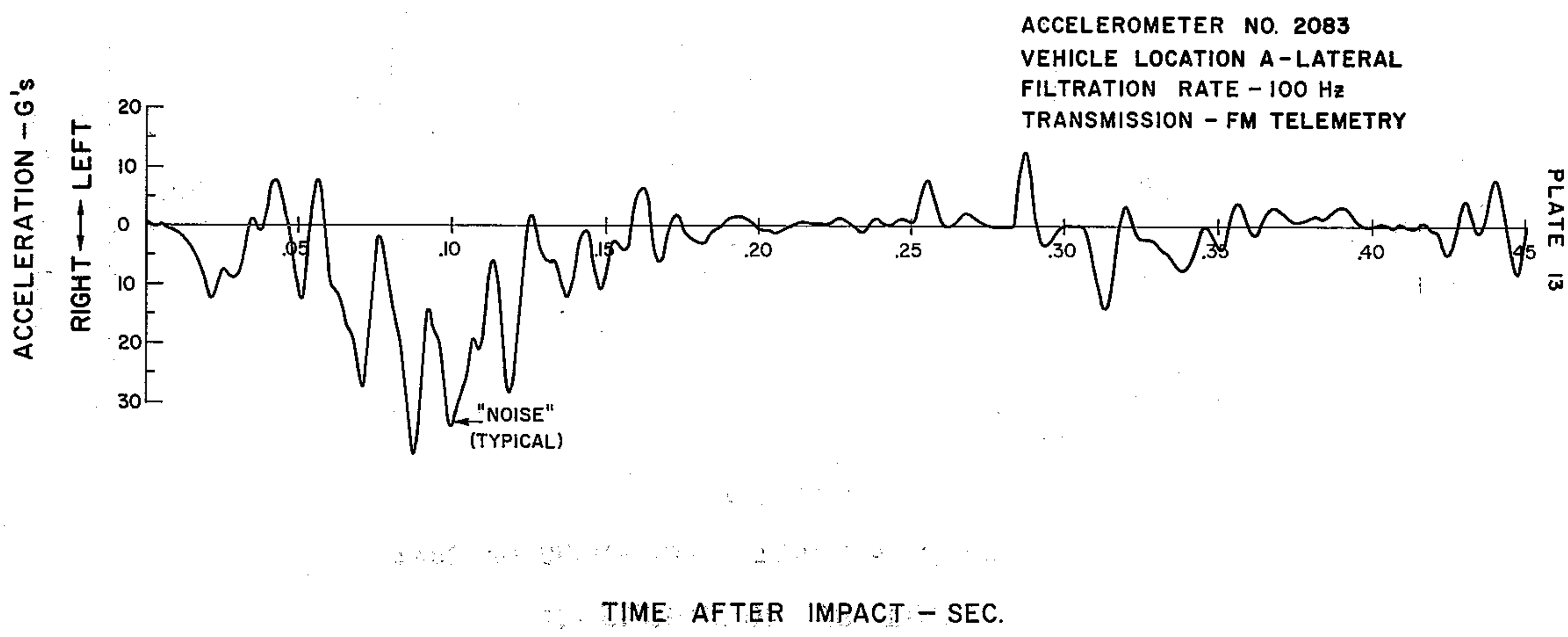
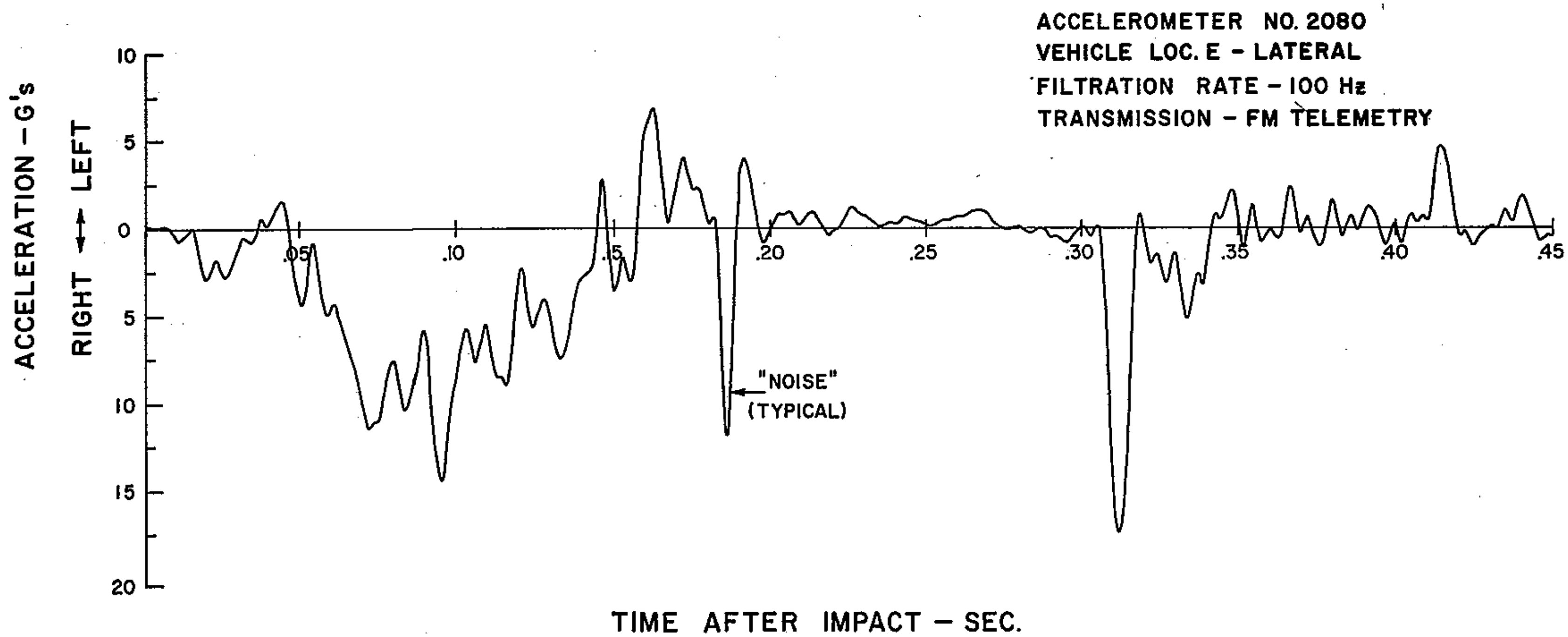


PLATE 14

ACCELERATION VS TIME

TYPE 20 BRIDGE RAIL TEST 235 CHANNEL 5

(66 mph/ 25°)



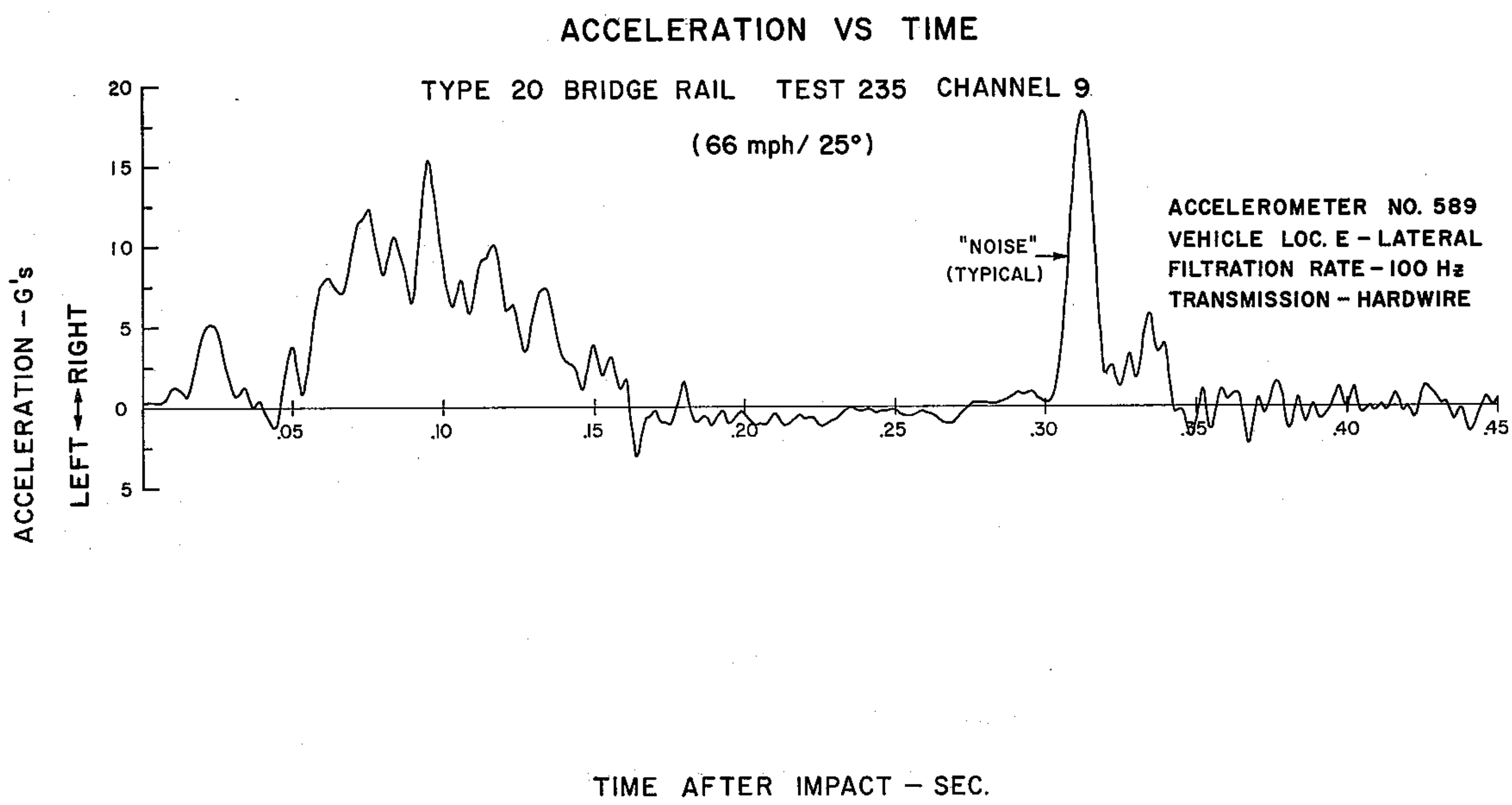

ACCELERATION VS TIME
TYPE 20 BRIDGE RAIL TEST 235 CHANNEL 9
(66 mph/ 25°)
ACCELEROMETER NO. 589
VEHICLE LOC. E – LATERAL
FILTRATION RATE – 100 Hz
TRANSMISSION – HARDWIRE
"NOISE" (TYPICAL)
ACCELERATION – G's
LEFT ↔ RIGHT
20
15
10
5
0
5
.05
.10
.15
.20
.25
.30
.35
.40
.45
TIME AFTER IMPACT – SEC.

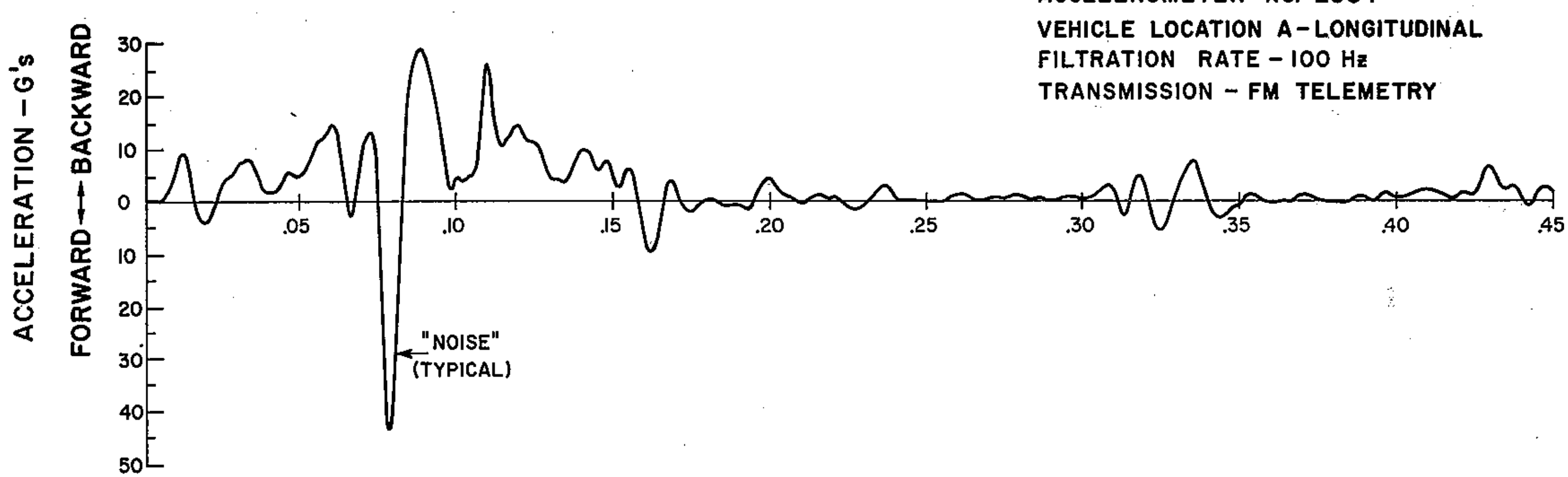
PLATE 16

ACCELERATION VS TIME

TYPE 20 BRIDGE RAIL TEST 235 CHANNEL 1

(66 mph/ 25°)

ACCELEROMETER NO. 2084
VEHICLE LOCATION A-LONGITUDINAL
FILTRATION RATE - 100 Hz
TRANSMISSION - FM TELEMETRY

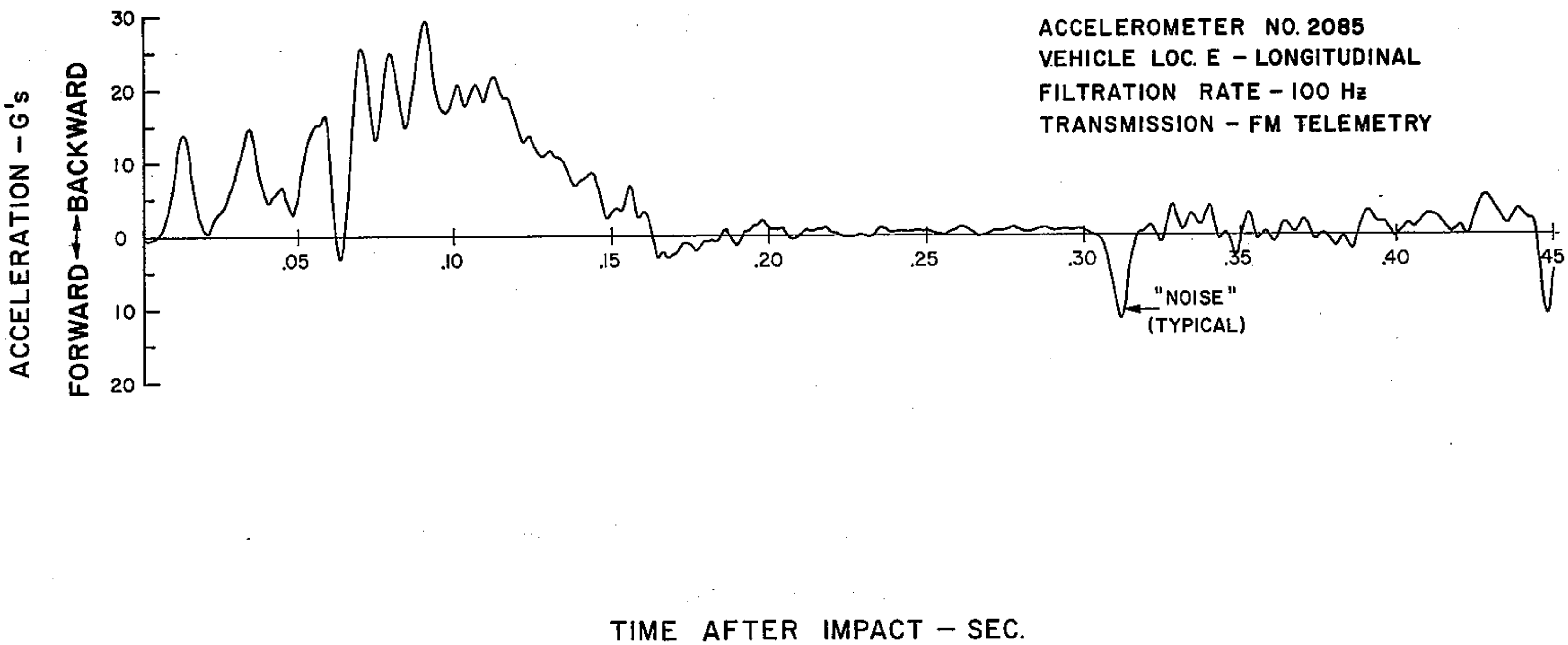


TIME AFTER IMPACT – SEC.

ACCELERATION VS TIME

TYPE 20 BRIDGE RAIL TEST 235 CHANNEL 3

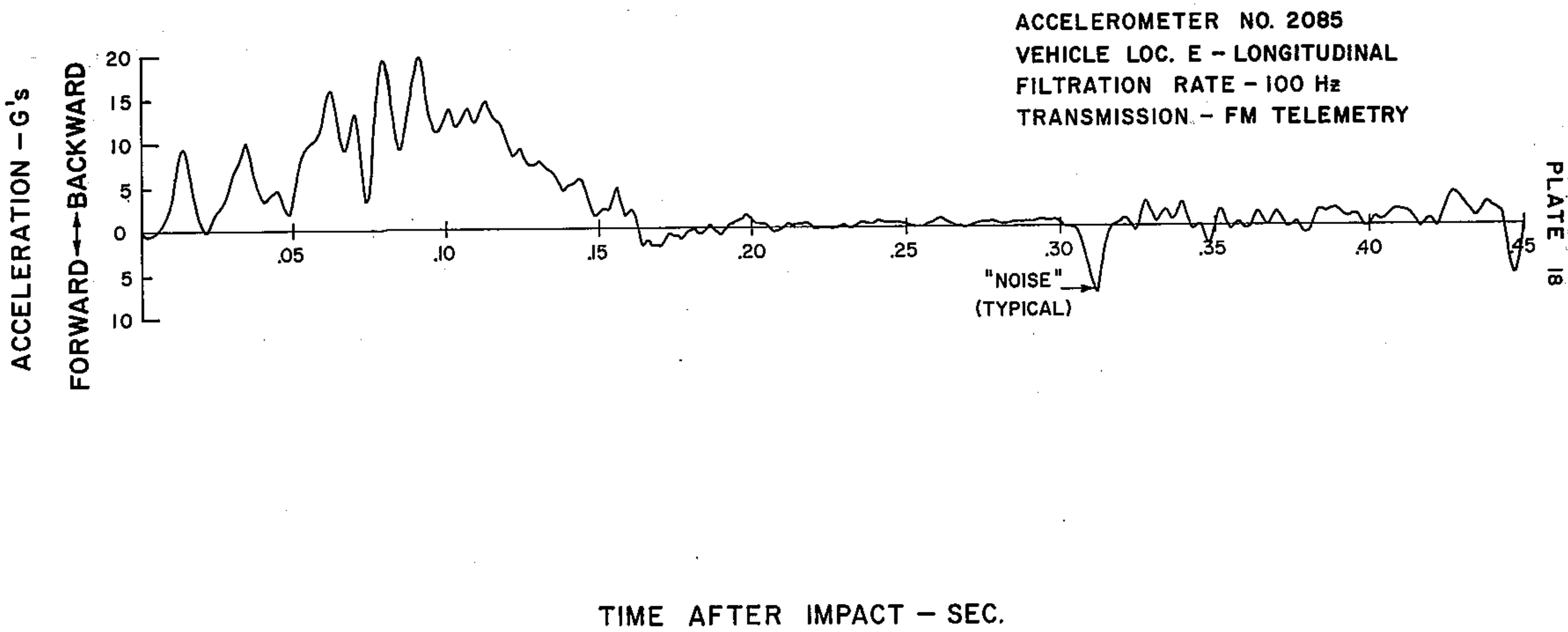
(66 mph/ 25°)



ACCELERATION VS TIME

TYPE 20 BRIDGE RAIL TEST 235 CHANNEL 4

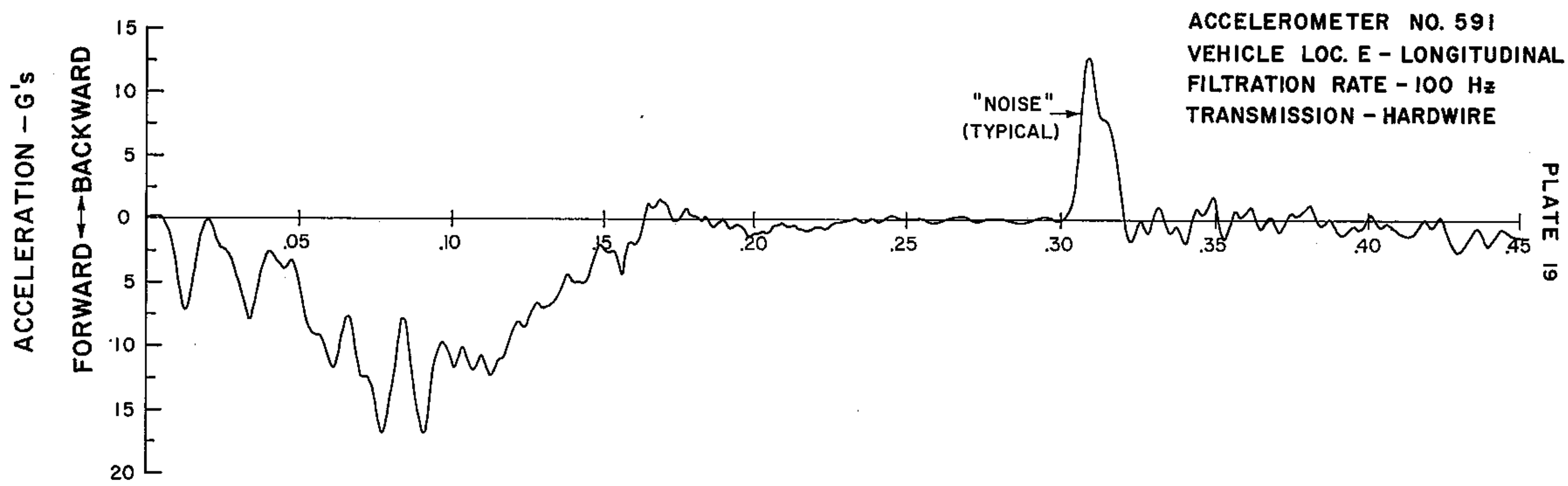
(66 mph/ 25°)



ACCELERATION VS TIME

TYPE 20 BRIDGE RAIL TEST 235 CHANNEL 8

(66 mph/ 25°)

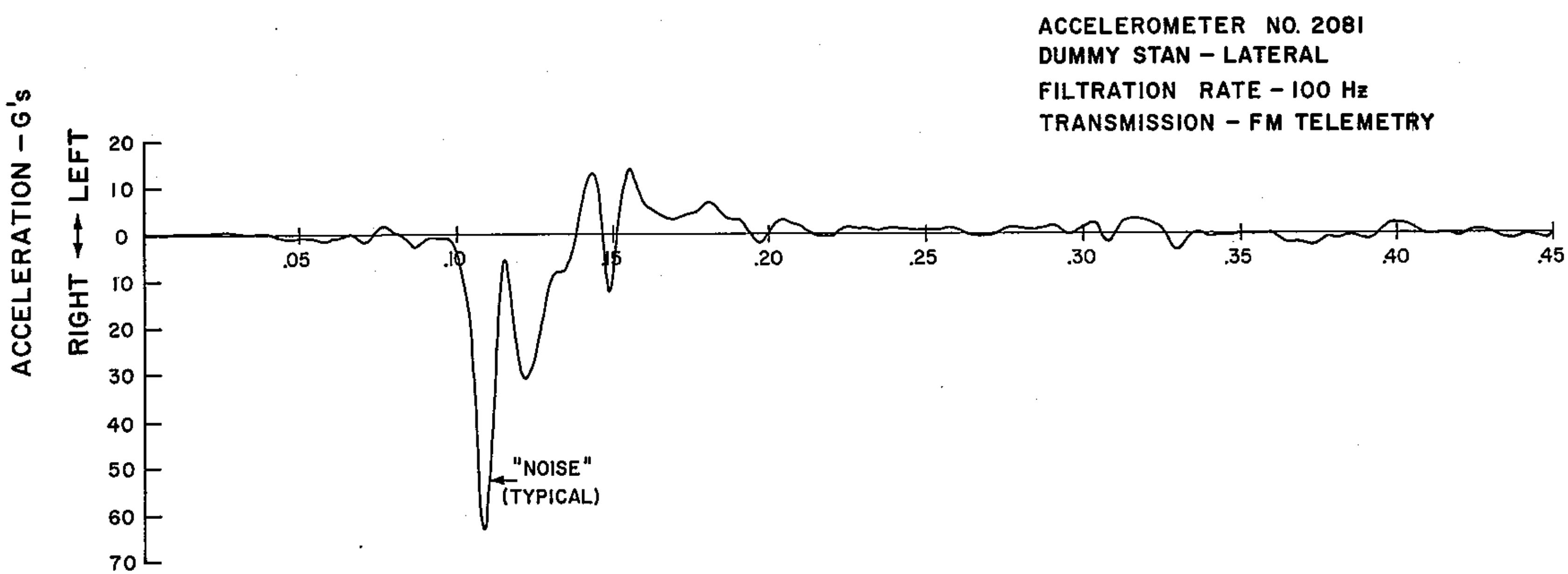


TIME AFTER IMPACT - SEC.

ACCELERATION VS TIME

TYPE 20 BRIDGE RAIL TEST 235 CHANNEL 6

(66 mph/ 25°)



ACCELERATION VS TIME

TYPE 20 BRIDGE RAIL TEST 235 CHANNEL 7

(66 mph/ 25°)